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BULLETINS ~~152~~-163

OF THE

Rhode Island

Agricultural Experiment Station

OF THE

Rhode Island State College

FOR THE

FISCAL YEARS

FROM

June 1913

~~JULY 1, 1912~~, to JUNE 30, 1915

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BULLETIN 155

Agricultural Experiment Station

OF THE

Rhode Island State College

KINGSTON, R. I., U. S. A., JUNE, 1913.

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AGRICULTURAL EXPERIMENT STATION OF THE RHODE ISLAND STATE COLLEGE.

BULLETIN 155*

STUDIES ON INHERITANCE IN POULTRY: I. THE CONSTITUTION OF THE WHITE LEGHORN BREED.†

PHILIP B. HADLEY,
WITH THE ASSISTANCE OF DOROTHY W. CALDWELL AND C. H. MAGOON.

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*This bulletin constitutes a part of the Twenty-sixth Annual Report for the year ending June 30, 1913.

†Contribution No. 19, from the Division of Animal Breeding and Pathology of the Agricultural Experiment Station.

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I. Introduction.

In the history of plant and animal breeding it has been commonly observed that the mating of different varieties or species may produce offspring which, in certain respects, are unlike either parent. In some instances the qualities of this mixed, or heterozygous, individual are an improvement upon either parent form, just as superior strains of corn are in reality hybrid-products, or as the crosses between certain varieties of poultry yield birds of different plumage or of larger size than that of either parent. In the continued propagation of these desirable types, the plant or animal breeders have, however, encountered much difficulty. This difficulty deals primarily with the following circumstance: In the majority of cases the heterozygous form does not breed true; upon continued propagation it breaks up again into the parent types, and leaves only a certain proportion of heterozygous individuals which themselves, when bred further, behave in the same manner.* In other words, no method is known of "fixing" a heterozygous character,—of causing it to faithfully reproduce itself through successive generations. That knowledge of such a method would be a valuable addition to the theory and practice of both plant and animal breeding, no one can deny; whether it is possible, remains to be ascertained.

The many variable features possessed by domestic poultry and the ease with which crosses between diverse types can be made, render this group of animals especially favorable for studying the behavior, in inheritance, of such so-called heterozygous characters. At the outset of this investigation, in 1909, *barring* in fowls was selected as the character to be studied. The barred color-pattern in feathers was then tentatively regarded as a heterozygous condition arising from the mixture of black and white. The problem was therefore, first of all, to produce this character *de novo,* as it were; or at least, to obtain it as a result of mating fowls which, in themselves or in their ancestry, were not known to possess the condition either in a fixed or in a transitional state; in other words, in selecting the material to be employed in the investigation, the use of Barred Plymouth Rocks and other barred breeds, as well as of their ancestors and their derivatives, was to be scrupulously avoided. Secondly, the problem was to so breed the birds manifesting the newly-produced character that it should be made a permanent acquisition of the breed.

---

*A case in point is that of the Blue Andalusian fowl which is a "hybrid" product and never breeds true.

As will appear in the following pages this end has in a measure been reached,—that is to say, a breed of barred fowl has been produced through the employment in breeding of factors found in birds which manifested no somatic barring. But the nature of the results secured is such as to call into question the truth of the very hypothesis upon which the investigation was originally based. In other words, the question is now raised whether we are justified in considering the type of barring revealed and studied in the experiments to be reported in the light of a heterozygous character. The recently-devised factor-hypothesis and its application to the principles of breeding and laws of heredity, together with the theory of unit-characters, has profoundly modified our views regarding the fundamental nature of the things that are inherited. Thus, to discover a factor for barring where it was not previously known to exist, and to produce such a factor (or such a pattern) *de novo* by the bringing together of simpler germinal elements, are manifestly two different operations. A discussion of the bearing of this consideration upon the results of the present investigation may well be deferred until the experimental data have been presented. It may be said here, however, that these data may not be valueless notwithstanding that their significance now appears to be different from that first assumed; and the investigation as a whole, though, perhaps not dealing with the actual "fixation" of a heterozygous character as first surmised may still have the merit of throwing new light upon one phase of the inheritance of the barred color-pattern; and, in addition, of producing a new type of fowl through the isolation, and subsequent employment in breeding, of a previously hidden factor.

The barred color-pattern is doubtless a very old and a by no means uncommon form of marking in the plumage of both wild and domestic birds. With some modification it is present in the feathering of many of our game birds, but it is in one or two varieties of domestic fowl that the character is to be seen in the purest and most extended form. At the present day the Barred Plymouth Rocks, an American breed, represent by far the most perfect development of the barred pattern to be found in any species or variety of bird.

The origin of barring in domestic fowls is not easy to ascertain. It appears probable that the barring used in making the breed of Barred Plymouth Rocks as it is known to-day was derived from the American Dominiques. These birds, which possess less perfect barring than the Barred Plymouth Rocks, are stated by some to have inherited this marking from the "cuckoo" birds of England, but this point is not supported by available evidence. It must therefore be concluded that we are not acquainted with the manner by whicn the definite barred color-pattern was first introduced into the breeds of domestic fowl. So far as can be ascertained, however, no new breeds of barred fowl have been produced since the making of the American Barred Plymouth Rocks, in which, as has been stated, the Dominiques were the major component. A partial exception to this statement is found in the words of Wright (1910), who states that barred birds are sometimes the result of crosses between white birds and those of dark color. Wright assumes that barring is not a primary character [unit character], but a sort of mixture through which the breed of Dominiques may have been founded. He further observes that when once produced, this character "has a strong tendency to permanence." These opinions of Wright were based upon observations made from time to time in the poultry yard and without especial study. Within the past few years, however, the method of inheritance of many characters in fowl has been made by several investigators the object of especial study and, among these characters, that of barring has received some consideration. We may therefore review briefly some of the recent work on this subject.

II. Historical Résumé.

Hurst (1905) was among the first to test the Mendelian principles of heredity with respect to characters of fowl. Although he did not make a particular study of barring he makes several references to the appearance of this color-pattern in cross-bred birds. Among other crosses was Houdan ♂ × White Leghorn ♀. This cross "gave 94 whites and 11 blacks; of these, 22 were apparently clear white, 72 white ticked with black, one black with white head, and 10 black ticked with white. In each case the tickings were slight and not extensive, so that in the ground color, the distinction between white and black was marked and discontinuous. In the first plumage all except two of the clear whites developed black ticks, similar to those that were born ticked; the blacks developed into 6 blacks and 5 'cuckoos;' 5 of the blacks were slightly ticked with white in the crest only, and in their plumage were indistinguishable from the Crève-cœur breed, the other black developed into a typical light Houdan; the 5 cuckoos were gray-white, barred with blue-black or white feathers; both the blacks and the cuckoos were distinctly shaded with brown. Curiously enough the 6 blacks were all pullets and the 5 cuckoos all cockerels!" But this result, as will be shown later, is wholly explainable on the ground that Hurst's White Leghorn ♀♀ were heterozygous for the barred plumage character, and that they were not pure for white.

Later, Hurst mated one of the cuckoo cockerels with two of the black pullets. From this mating, 43 chicks were hatched, all with black down-feathers. But 34 were ticked with white, 7 had white heads and 2 were strongly shaded gray. Of those hatched, 31 were reared and gave, in the first plumage, 17 cuckoos and 14 blacks. "Of the cuckoos, 7 were cockerels and 10 were pullets, and of the blacks, 8 were cockerels and 6 were pullets, so that the correlation of black with ♀ and cuckoo with ♂ in F_1 was not maintained in F_2." Hurst states further that "the cuckoos were precisely similar to those of F_1, having a gray-white ground barred with blue-black, with odd black or white feathers. . . . The blacks were of two types, dark Houdans and Crèves, suggesting that the cuckoo male parent was giving off black gametes. No dominant whites appeared in this mating, suggesting that the cuckoo male parent was *not* giving off dominant white gametes."

It is interesting to note that the cuckoo ♂ mentioned above subsequently moulted into almost clear white, only one feather on the back being tipped with gray.

Besides the Houdan × White Leghorn cross, Hurst also crossed Black Hamburg ♂ with White Leghorn ♀. The progeny comprised 49 whites and 8 blacks; of these one was apparently clear white, 48 were ticked with black, and 8 were black with whitish throats. None of these chicks were raised for further observation, and Hurst draws no conclusions regarding the origin of the barred pattern described.

Davenport (1906) has also described a type of barring which appeared when certain black and white breeds were crossed. In these matings dominance of white was the usual result. Two White Leghorns crossed by a Black Minorca produced in F_1 only white birds, the ♀♀ having some black feathers White Leghorns crossed with Houdans gave only white progeny This result is at variance with Hurst's mentioned above. White Leghorns crossed with Red-backed game had "white offspring with some buff on breast." "On the other hand," Davenport continues (p. 75), "the white color of the Silky dominates over the dark color of the Frizzle in about only 23 per cent. of the hybrids."

Davenport states further that no barring resulted from crossing White Leghorn with Houdan or with Black Minorca. Barring in the male progeny did appear, however, in matings between the Tosa fowl and White Cochin, between White Leghorn Bantam and Dark Brahma, and in matings between White Leghorn Bantam and Rump-less Game. "Of 26 hybrids between Black Cochin and White Leghorn, 8 were barred black and white, and these belonged equally to the two sexes."

With reference to barring, Davenport in his 1906 report concludes as follows: "Barring is a heterozygous condition found in hybrids from a white and black parent. It is provisionally regarded as a form of particulate inheritance as opposed to the alternative inheritance of the Leghorn × Minorca cross. This heterozygous condition when interbred, usually breaks up into white, uniformly pigmented, and barred, as in the case of the Tosa × White Cochin hybrids." As to the inheritance of white and dark plumage, Davenport states: "Aside from cases of barring and Andalusian coloration, white usually dominates over dark plumage. This is true in all cases where White Leghorn is employed as a white race, whether the other race is Game, Dark Brahma, Houdan or Minorca. When the Silky is used as the white race, white is sometimes recessive, but it must be acknowledged that the dark parents were not the same as were used with the Leghorn, but were a Game, Frizzle and Jungle fowl; consequently the results in the two series are not strictly comparable. . . . It is hardly conceivable that the white of the Silky is different from that of the Leghorn; so it must be concluded that the white inherited as a solid color is sometimes dominant and sometimes recessive, depending upon the race in which it inheres." On this point, we now have further light as will be indicated later in this paper.

In Davenport's later report (1909) upon inheritance of characteristics in domestic fowl, the application of the factor hypothesis is strongly evident, and, in the light of later researches, several of his earlier conclusions are modified or the results receive a somewhat different interpretation.

Among the Black × White crosses reported in this paper is the cross White Leghorn (♂?) × Black Minorca (♀?). In 154 offspring there appeared 116 white, black-white, or blue, and 38 black. Some of the latter contained more or less white, and among them were four barred birds. This result approximates very closely the expected F_1 Mendelian ratio.* Since the birds that are heterozygous for white and black appear white, we have 75 per cent. of white birds. Apparently Davenport was not working with the pure-bred White Leghorn stock.

In a cross between White Leghorn and Black Cochin there appeared among 24 offspring, 10 white, 7 black and 7 barred. In this case Davenport assumes that the Leghorn was heterozygous for white (since half the progeny were not white) and heterozygous for barring. Subsequently the barred birds which resulted from the above cross, were mated together. This cross gave 23 white birds, 40 blacks or games, and 21 spangled, barred or blue. Regarding this result Davenport says: "On the assumption that the zygotic formula of both hens and cocks is BbN_2Ww (compatible with barred plumage), we get four-sixteenths of the offspring white, three-sixteenths mottled or barred, and nine-sixteenths black or game, thus approximating the observed result; *i. e.*, 21, 16, 47, as compared with 23, 21, 40. The result supports the hypothesis of a barring factor, B."

That Davenport obtained barred birds in a cross between White Leghorn Bantam and Dark Brahma has already been mentioned: Of 51 F_1 birds, 5 were barred. An attempt was made to fix the barring. The best cock bred from F_2 and the best females from F_1 or F_2 were used for the experiment. From this cross there were obtained 3 whites, 67 blacks, 37 of Dark Brahma type and 38 barred birds. "This result," says Davenport, "suggests the interpretation that one of the parents, probably the male, contains both heterozygous black and barring, while the other parent lacks the supermelanic coat and has homozygous barring. Then, of the offspring, half will be barred and half will be black, and consequently (since only the non-black show their barring), one-fourth will appear barred, one-fourth will appear of the Dark Brahma type and half will be pure black, or have the pattern obscured by the supermelanic coat."

Besides the studies on barring reported above, dealing chiefly with crosses between light and dark birds, the barring of the Plymouth

---

*Provided that the White Leghorns were heterozygous for white.

Rock breed of fowls has, within the past two or three years, received some consideration.

The fact has long been noticed by observant poultrymen that the progeny from crosses between Plymouth Rocks and dark non-barred breeds varied with respect to the barred color-pattern, according as the male bird belonged to one or the other race in question. Cushman (1893) was probably the first to report this circumstance. This writer made a large number of crosses between pure-bred fowls with the purpose of perfecting a good market roaster. Among his crosses were Indian Game ♂ × Barred Plymouth Rock ♀. Cushman (*l. c.*) gives a brief description of this cross and states that the cockerels had barred plumage whereas the pullets were all black.

It is probable that other poultrymen have observed similar results from such crosses, but without recording their observations. Yet the facts observed awakened little speculation until the attempt was made to place upon them an interpretation agreeing with the Mendelian view of heredity. Spillman (1908) then devised a Mendelian hypothesis to account for the facts observed in the inheritance of barring. This hypothesis may be briefly stated as follows:

1. When barring is present in *female* birds, they are heterozygous for this character; they are also heterozygous for the female sex character (*F*).

2. When barring is present in *male* birds, they may be either *heterozygous* or *homozygous* for this character; the males are always homozygous for the absence of the female sex character.

3. Barring (*B*) and the character, "femaleness" (*F*), never exist together in the same gamete.

This may be represented symbolically as follows:

Let *F* represent the female sex character (♀).

Let *f* represent the absence of femaleness, or the male sex character (♂).

Let *B* represent the factor for barring.

Let *b* represent the absence of the barring factor.

Employing these symbols, the zygotic formula of the Barred Plymouth Rock ♂ becomes

$$BBff,$$

forming gametes

$$Bf \cdot Bf$$

The zygotic formula of the ♀ becomes

$$BbFf,$$

forming gametes

$$Bf \cdot bF$$

since, by hypothesis, B and F (or their complementary combination, bf), cannot be present in the same gamete.

The matings occurring in the propagation of pure Barred Plymouth Rock stock would therefore be represented:

$$\begin{array}{c} \text{♂}\ Bf \cdot Bf \times \\ \underline{\text{♀}\ Bf \cdot bF =} \\ \text{♀♀}\ BbFf, \text{ Barred} \\ \text{♂♂}\ BBff, \text{ Barred} \end{array}$$

the ♀♀ being heterozygous for barring and the ♂♂ homozygous.

If, however, we have the mating between the Barred Plymouth Rock and some dark non-barred breed, such as the Rhode Island Red, the case is different, and the results vary accordingly as the ♂ is chosen from one breed or the other.

The zygotic formula of the R. I. Red ♂ (non-barred) would be

$$bbff,$$

forming gametes:

$$bf \cdot bf$$

while the formula of the Barred Rock ♀ is as shown above. This mating would therefore become:

$$\begin{array}{c} \text{♂}\ bf \cdot bf \times \\ \underline{\text{♀}\ bF \cdot Bf =} \\ \text{♂♂}\ Bbff, \text{ Barred} \\ \text{♀♀}\ bbFf, \text{ Black} \end{array}$$

In other words the ♂♂ would be barred (heterozygous) while the ♀♀ would be black.

The reciprocal cross would be represented

♂ $Bf \cdot Bf$ ×
♀ · $\underline{bF \cdot bf}$ =
♂♂ $Bbff$, Barred
♀♀ $BbFf$, Barred

both ♂♂ and ♀♀ being heterozygous for barring. In other words, all progeny are barred when the ♂ parent is homozygous for this character.

That Spillman's hypothesis could be verified in experimental results was first shown by Goodale (1909) in a brief paper reporting the results of matings between Buff Rocks and Barred Plymouth Rocks. In a subsequent note, Goodale (1910) states that in crosses between White Leghorn (♀) and White Plymouth Rock (♂), only white birds appeared in F_1; in a few of these faint bars developed. In F_2, however, there were white, black, gray and barred chicks, the latter resembling exactly the Barred Plymouth Rocks.

In addition to the instances of barring mentioned above, Pearl (1912) has reported, upon the authority of an English fancier*, the history of the "Cuckoo Pekins." This bantam breed, according to the authority cited, was produced from a mating of Black Pekin (♂) with White Booted (♀). One of the ♀ progeny showed "stone-colored bars on a milk-white ground." This bird was mated back to its sire, the Black Pekin. The cuckoo pullets from this mating were mated with a cuckoo cockerel derived from imported Chinese Cuckoo stock. Inbreeding was practiced until a permanent cuckoo variety was established. Regarding the origin of this barred pattern, Pearl assumes that it did not arise *de novo*, but that the barred factor was present in the White Booted parent. However this may be, one further point is of interest, namely, the question of the alleged transmission of barring from the White Booted ♀ to her daughter. As will be shown later, this is contrary to the established method of inheritance of barring as it occurs in the Barred Plymouth Rock breed; and without more convincing evidence the case does not appear to warrant the assumption that barring of this sort is inherited in any other manner than that now generally accepted.

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*Mr. William F. Entwisle, who has published the account in his book, "Bantams," Wakefield, England, 1894 (?), p. 1-116.

III. Experimental Results.

As has been stated, at the outset of this investigation barring was tentatively regarded as a heterozygous condition resulting from the mating of black with white fowls. Therefore the preliminary experiment involved chiefly the mating of these breeds with the aim of securing from some of the crosses a certain number of individuals possessing the barred color-pattern. These crosses were between the White Leghorn ♂ and the following black ♀♀: White-faced Black Spanish, Black Minorca, Black Langshan, Black Java, Black Hamburg and Black Cochin. The F_1 generation was bred in 1910. In 1911, the F_1 breeding was continued and in addition a number of the F_2 generation from some of the crosses were reared. In 1912, a greater number of the F_2 generation were reared, and also a number of other crosses were made between selected F_2 stock and several other varieties of fowl. It may be said in passing that all the stock used in the experiments was carefully selected from reputable breeders and was probably as pure-bred as any that could be obtained in the country. The breeds mentioned were chosen for the experiments first of all, because so far as could be ascertained from poultry literature none of them was known to be related to breeds possessing the barred color-pattern such as the Barred Plymouth Rocks or the Dominiques. The modern White Leghorn, though differing considerably from the older type, is usually stated to be a breed which has been mixed with others only to a slight extent; and it is therefore commonly regarded as "one of our purest breeds." As will be demonstrated later this conception is rather doubtful. So much regarding race-purity is not usually said of the Black Hamburgs, Black Minorcas, Black Javas, Black Cochins, and Black Langshans, although the Black Spanish breed has probably been kept fairly pure. In no case, however, is it positively known that barred stock has entered into the formation of these breeds. It was therefore at first assumed that the appearance of barring in the progeny from these birds would indicate that this pattern had been formed *de novo* as a heterozygous condition, or that it was inherited from the white stock in which it existed as a cryptomere as in the case of the White Plymouth Rock breed. Whether this was a justifiable assumption will appear in the course of the experiments now to be described.*

CASE 1.—*White Leghorn ♂ × Black Hamburg ♀.* Nature of mating: *CCBBffII × CCbbFfii.* (For discussion, see p. 186).

> *White Leghorn ♂ 193A:* Weight 5½ lbs., back of medium length; squirrel tail; body medium length, high on legs; high comb with six points, slightly thumb-marked and blade deficient in size; head long, eyes red; ear-lobes white but spotted with red; wattles of medium size with one fold in each; neck white with tendency to cream; back white; shanks, toes and beak pale yellow; spurs about one inch in length; no pattern observable on any of the feathers, which are also free from black ticking. (See Pl. I).
>
> *Black Hamburg ♀, 185A†:* Weight 4$\frac{3}{16}$ lbs., neck of good length; back long; tail carried high; body long but not deep; comb of good size, rather flat on top, spike with marked up-turn at rear; eyes dark hazel; ear-lobes bluish white and about half red; wattles very small, fine texture, smooth. Feathers of neck greenish black with purple barring; primaries dull black, secondaries and main tail feathers greenish black with some purple barring; body dull black; shanks dark slate; spurs about $\frac{1}{3}$ inch long. (See Pl. III).

The data on the first set of W. L. × B. H. matings are summarized in the following table:

---

*It will be convenient to include in the present section only the actual experimental results. All discussion of the significance of these results, together with their explanation, is taken up in Section IV, p. 182.

†Black Hamburg 186A resembled 185A in nearly all points.

TABLE 1.—Showing the results in F_1 of crossing White Leghorn ♂ × Black Hamburg ♀♀ (1910 series.)

MATING NUMBER.	PARENTS.		PROGENY.		
	♂	♀	White.	Black.	With barred feathers.
201	193 A	185 A	22	0	1 ♂ 1 ♀
202	193 A	186 A	8	0	....
211	193 A	*	19	0	2 ♂♂

*Female not identified, but one or the other of the above.

The data presented in Table 1 demonstrate that the white of the W. L. in all instances dominated over the black of the B. H. The progeny were not all pure white, however, since more than one-half of the F_1 generation (♂♂ and ♀♀ equally) showed black flecks in the white feathers. When the chicks were in down-feather the majority revealed one or more patches of black down on head, back or sides. Table 1 also shows that of the 49 birds recorded, 4 possessed one or more barred feathers, which were usually located on the back or among the wing coverts. In these cases the barring was usually clear and definite, although the pattern never reached to the base of the feather and frequently covered only the tip. No bird in F_1 was found to possess more than two or three such barred feathers. Of the four birds so characterized, three were ♂♂ and one was a ♀. In addition it should be noted that one bird showed a buff half-moon-shaped splash at the tip of one of the saddle-feathers.

Subsequent to making the series of crosses mentioned above, a second series was obtained in 1911. In this case one of the two B. H. ♀♀ was employed, but another W. L. ♂ was used, and B. H. ♀♀ from a different source were also introduced. The result of these matings is shown in Table 2.

TABLE 2.—Showing the results in F_1 of the second series of White Leghorn × Black Hamburg matings (Series of 1911).

MATING NUMBER.	PARENTS.		PROGENY.				
					With barred feathers.*		
	♂	♀♀	White	Black	♂	♀♀	?
8	1 A	4 A	14	0	1	4	0
9	1 A	5 A	4	0	0	1	0
10	1 A	6 A	9	0	0	0	0
11	1 A	7 A	20	0	0	0	1
27	1 A	186 A	14	0	1	1	0
Totals			61	0	2	6	1

*These birds are also listed in the white column since their plumage was mainly white (see text).

From Table 2 it appears that of 61 F_1 birds, all were white; but that 9 possessed one or more barred feathers. Of these 9, 6 were ♀♀, 2 were ♂♂, and the sex of the other was not ascertained. In this series there was about the same proportion of birds flecked with black and these were evenly distributed between the sexes.

CASE 1a.—[*White Leghorn ♂ × Black Hamburg ♀*] ♂ × [*White Leghorn ♂ × Black Hamburg ♀*] ♀. Nature of mating: *CCBbffIi* × *CCBbFfIi*. (For discussion, see p. 192).

Of the cross-bred fowls raised in 1910, ♂ $211M_2$ and six ♀♀ were bred together in 1911.

> The cockerel was hatched as a pure white bird without trace of black down-feathering. Among the coverts of each wing was a single feather showing a buff-yellow bar; among the saddle feathers were a few showing some buff.
>
> Among the ♀♀, 201 G was a nearly pure white bird but showed a few splashes of black in wing coverts and saddle feathers; 201 L was hatched with a large patch of black down

feathers on the back, but became a pure white bird; 202 G showed many black-splashed feathers on back and wings; 211 B showed a very small amount of black ticking; 211 K was a pure white bird; 211 V showed a small amount of black ticking.

TABLE 3.—Showing the results obtained in F_2 from the mating of White Leghorn × Black Hamburg cross-breds (1911 series).

MATING No.	♀♀	Total progeny.	White.	BLACK.			BARRED.			GRAY.
				♂	♀	?	♂	♀	?	
314	201 G	30	21	0	6	0	2	0	1	0
315	201 L	22	16	0	1	0	2	0	3	0
316	202 G	6	5	0	1	0	0	0	0	0
317	211 B	17	15	0	1	0	0	0	1	0
340	211 K	23	18	0	0	2	0	0	0	3
341	211 V	19	15	0	0	1	0	2	0	1
Actual totals		117	90	0	9	3	4	2	5	4
Expected totals		....	$87\frac{12}{16}$	$7\frac{5}{16}$			$21\frac{15}{16}$			......

The data presented in Table 3 show that the F_2 generation of W. L. × B. H. cross-breds is composed of black, white, gray and barred birds. If the gray, black and barred be considered together as "dark" individuals, it is then apparent that this group represents about one-fourth of the total number of fowls, while the group of white birds represents about three-fourths. This result is what we should expect in case of a pair of allelomorphic characters. It is evident that the white birds, although all appearing alike, include two sorts,—pure dominants (white), and birds that are heterozygous for black (usually flecked).

In 1912, another F_1 ♂, 8 L, was mated with 12 F_1 ♀♀. Both ♂ and ♀♀ resembled closely those used in the 1911 series of matings.

TABLE 4.—Showing the results obtained in F_2 from the mating of White Leghorn × Black Hamburg cross-breds (1912 series).

MATING NO.	♀♀	Progeny. (Total).	White.	BLACK.			BARRED.		
				♂	♀	?	♂	♀	?
456	8 B, G, H, I	18	13	0	1	0	2	1	1
457	9 C	13	8	0	1	0	3	0	1
458	10 H, I	14	10	0	1	0	2	1	0
459	11 B, E, G	25	21	0	0	0	2	1	1
460	201G, L	67	54	0	3	1	5	3	1
Actual totals		137	106	0	6	1	14	6	4
Expected totals		....	$102\frac{12}{16}$	0	$8\frac{9}{16}$	....	$17\frac{2}{16}$	$8\frac{9}{16}$	....

It is further apparent in Table 4 that among the "dark" birds, the blacks (including the grays) and barred birds appeared in the ratio 7 : 24. It should be said here, however, that several of the chicks which are recorded as black were described when they were in down-feather. It is certain that had they lived barring would have appeared in some of them, and the ratio of barred to black birds would have been changed somewhat in favor of the barred group.

There was a marked variation in the amount of barring present in the barred individuals. The pattern invariably found clearest expression in the hackle feathers, wing coverts and tail coverts; the primaries always showed a barring that was inferior to that of the secondaries. It was also observed that the ground-color of the feathers was not so light as in the case of feathers from a Barred Plymouth Rock, but contained more gray or blue-gray, so that the pattern was less distinct. But aside from these differences the type of barred pattern observed in F_2 differed in no important respect from that present in the Barred Plymouth Rocks. It corresponded well with the barring depicted in early illustrations (see Pearl, 1911, p. 306) of the Barred Plymouth Rock breed as it existed years ago, before it had been developed to the present state of perfection.

As has been stated, it is impossible to ascertain when chicks are in the down whether they may later develop barring. For this reason the ratio of black to barred birds as expressed in Table 3 probably does not represent the actual ratio. In order to avoid this source of error, there was made in 1912 a second series of crosses between F_1 W. L. × B. H. stock, reared in 1911 from new birds not employed in the 1910 matings. In compiling the records of these F_2 individuals no bird that was less than 3 weeks of age was entered. This precaution made it possible to discriminate carefully between black and barred birds, and results in some difference in the totals.

The results of this series of matings (Table 4) were essentially the same as in the 1911 series, save in the black : barred ratio. The barred birds showed the same sort of barring and all circumstances indicated that the appearance of this character in F_2 was in accordance with some definite law. This point is discussed in detail on p. 193, and we may now turn our attention to the results of other crosses involving the W. L. stock.

CASE 2.—*White Leghorn* ♂ × *Black Spanish* ♀. Nature of mating: *CCBBffII* × *CCbbFfii*. (For discussion, see p. 186).

In this series of matings the results of the 1910 and 1911 breeding are combined. In 1910, W. L. 193 A was employed; in 1911, W. L. 1 A.* In the 1910 matings, Black Spanish ♀♀ 181 A and 182 A were employed.† In 1911 B. S. ♀♀ 13 A, B and C were used.‡ The Black Spanish ♀ 181 A, typical of the others, was described as follows:

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*Obtained from Charles J. Fogg, Waltham, Mass.

†Obtained from the Groesbeck Poultry Farms, Hartford, Conn.

‡Obtained from M. H. Lindsey, Northville, N. Y.

Black Spanish ♀, *181 A:* Weight 4$\frac{3}{16}$ lbs., neck long, back of medium length; body of medium length, set well on legs; comb upright, four points, fine texture; head long and face deficient in white; eyes dark hazel; wattles are smooth and have a fine texture; wing coverts, back and tail coverts black with purple barring; primaries, secondaries and main tail feathers are dull black; body feathering has a dark brown cast; under-color dark slate.

TABLE 5.—Showing the results in F_1 of White Leghorn × Black Spanish matings (1910 and 1911 series).

MATING NO.	♂♂	♀♀	Total progeny.	White	With barred feathers.
197	193 A	181 A	10	10	0
198	193 A	182 A	24	24	0
14	1 A	13 A	18	18	1 ♀
15	1 A	13 B	1	1	1 ♂
16	1 A	13 C	6	6	1 ♂
Actual total			59	59	3

A glance at Table 5 makes it evident that the white of the W. L. dominated over the black of the B. S. as it did over the black of the B. H. The dominance was not perfect, however, since a small number of birds showed black fleckings; and three possessed feathers which were distinctly barred. These barred feathers appeared as follows: In one case two right secondaries and one tail feather had a single gray band across the tip. These barred secondaries remained in the adult plumage, but the barred tail feather was lost. In the second case the barred pattern was faintly present in one of the saddle feathers. In the third case a bird put up one barred wing covert which was moulted and never replaced.

CASE 2a.—[*White Leghorn* ♂ × *Black Spanish* ♀] ♂ × [*White Leghorn* ♂ × *Black Spanish* ♀] ♀. Nature of mating: *CCBbffIi* × *CCBbFfIi.* (For discussion, see p. 193).

In 1911 one of the cross-bred ♂♂ (198 B) was bred to five of the cross-bred ♀♀ (197 K, 198 E, 197 A, 197 G and 198 A). The ♂ 198 B was white except for a very faint ticking of black on a few feathers. The 5 ♀♀ resembled the ♂ in all points of plumage. In 1912, the same ♂ was mated to 3 of the 1910 cross-breds and to 3 of the F_1 cross-bred ♀♀, produced in the 1911 matings between W. L. and B. S. stock. The results of these matings are presented in Tables 6 and 7.

TABLE 6.—Showing the results obtained in F_2 from the mating of White Leghorn × Black Spanish cross-breds (1911 series).

MATING No.	♂	♀♀	Total progeny.	White.	BLACK.			BARRED.			Gray.
					♂	♀	?	♂	♀	?	
19	198 B	197 K	11	10	0	1	0	0	0	0	0
311	198 B	198 E	28	22	0	2	0	3	0	0	1
310	198 B	197 A	23	19	0	2	0	0	0	0	2
20	198 B	197 G	16	13	0	2	0	0	1	0	0
21	198 B	198 A	12	11	0	0	0	0	0	1	0
Actual totals			90	75	0	7	0	3	1	1	3
Expected totals			....	$67\frac{8}{16}$	0	$5\frac{10}{16}$	...	$11\frac{4}{16}$	$5\frac{10}{16}$	...	......

In 1912, similar matings between W. L. × B. S. cross-breds were made with the results shown in Table 7. Combined results for the two years are given in Table 8.

TABLE 7.—Showing the results obtained in F_2 from the mating of White Leghorn × Black Spanish cross-breds (1912 series).

MATING No.	♂	♀♀	Total progeny.	White.	BLACK.			BARRED.			Gray.
					♂	♀	?	♂	♀	?	
467	198 B	14 D, S, T	85	69	0	6	2	7	1	0	0
468	198 B	197 A, G	65	61	0	4	0	0	0	0	0
469	198 B	198 E	41	31	0	3	0	4	0	0	3
Actual totals			191	161	0	13	2	11	1	0	3
Expected totals			....	$143\frac{4}{16}$	0	$11\frac{15}{16}$	..	$23\frac{14}{16}$	$11\frac{15}{16}$	..	.....

TABLE 8.—Combined results from Tables 6 and 7.

SERIES.	Total progeny.	White.	BLACK.			BARRED.			Gray.
			♂	♀	?	♂	♀	?	
1911	90	75	0	7	0	3	1	1	3
1912	191	161	0	13	2	11	1	0	3
Actual totals	281	236	0	20	2	14	2	1	6
Expected totals	....	$210\frac{12}{16}$	0	$17\frac{9}{16}$	....	$35\frac{2}{16}$	$17\frac{9}{16}$	....	......

We thus observe from the results presented in Tables 6, 7 and 8 that barred birds made their appearance in the F_2 generation of the W. L. × B. S. cross. The fairly wide departure from the expected ratios will be discussed on a later page.

CASE 3.—*White Leghorn* ♂ × *Black Minorca* ♀. Nature of mating: *CCBBffII* × *CCbbFfii*. (For discussion, see p. 186).

The ♂ used in this experiment was 193 A, previously described.

> *Black Minorca* ♀, *183 A:* Weight $6\frac{1}{16}$ lbs., neck flat, back of good length; body of medium length; comb, large with serrated blade, five points,—falls half on each side; eyes light hazel; ear-lobes bluish white, mottled with red; wattles of fine texture, small; wing-coverts and tail-coverts greenish with purple barring; primaries, secondaries and main tail feathers are dull black; body feathers are very dark brown; under-color slate; shanks are dark slate. Black Minorca ♀ 184 A was similar in all important respects to 183 A.

As a result of this cross all the F_1 birds were white. Many showed black tickings and one ♂ put up a barred feather. This bird was hatched as a white chick with a small patch of black down on the back. Later a buffy tinge developed over some of the wing coverts.

CASE 3a.—[*White Leghorn* ♂ × *Black Minorca* ♀] ♂ × [*White Leghorn* ♂ × *Black Minorca* ♀] ♀. Nature of mating: *CcBbffIi* × *CcBbFfIi*. (For discussion, see p. 193).

Of the W. L. × B. M. cross-breds raised in 1910, ♂ 200 C, which put up one barred feather the first year, was mated in 1911 with two of his sisters, 199 E and 200 D. These two ♀♀ were white but showed many feathers that were ticked with black. The results of this cross are presented in Table 9.

TABLE 9.—Showing the results obtained in F_2 from the mating of White Leghorn × Black Minorca cross-breds.

MATING NO.	♂	♀♀	Total progeny.	White.	BLACK.			BARRED.		
					♂	♀	?	♂	♀	?
312	200 C	199 E	10	9	0	0	1	0	0	0
313	200 C	200 D	7	5	0	1	0	1	0	0
Actual totals			17	14	0	1	1	1	0	0
Expected totals			....	$12\frac{12}{16}$	0	$1\frac{1}{16}$	...	$2\frac{2}{16}$	$1\frac{1}{16}$	...

From the data presented in Table 9 it is apparent that, as was the case with the W. L. × B. H. and the W. L. × B. S. cross-breds, here also we have both black and barred birds thrown out in F_2. But, whereas in the earlier matings the dark : light ratio came very close to Mendelian expectations, in the present case the departure is more noticeable. It is probable, however, that observation of a larger number of birds would have yielded results closer to the expected.

The one barred bird resulting from this cross, 313 C, was a ♂. Its general coloration was gray but barring was well manifested in feathers of the hackle and back and in the wing coverts. No barring was present in the primaries but it could be distinguished faintly in the secondaries.

CASE 3b.—[*White Leghorn* ♂ × *Black Minorca* ♀] ♂ × *Black Minorca* ♀. Nature of mating: *CcBbffIi* × *CCbbFfii*. (For discussion, see p. 194).

In addition to the foregoing, the results of a cross between an F_1 ♂ and pure-bred, Black Minorca ♀♀ may be reported. The ♂ 200 C as previously stated showed on the right flank a feather barred over one-half. The B. M. ♀♀ were those used in the F_1 matings. In Table 10 are presented the data relative to this back-cross.

TABLE 10.—Showing the results of the cross: [White Leghorn ♂ × Black Minorca ♀] ♂ × Black Minorca ♀.

MATING NO.	♂	♀♀	Total progeny.	White.	BLACK.		BARRED.	
					♂	♀	♂	♀
325	200 C	183 A	5	3	0	1	1	0
326	200 C	184 A	1	0	0	1	0	0
Actual totals			6	3	0	2	1	0
Expected totals				3	¾	¾	¾	¾

In Table 10 it is shown that of 6 birds resulting from this cross 2 were black ♀♀ and one was a barred ♂. The latter developed into a well barred adult bird (325 B). The pattern was clearest in wing coverts, tail coverts and hackle feathers. On the primaries barring was faint but clearer on the secondaries. The general coloration was slightly brownish.

CASE 3c.—♂ $\left\{\dfrac{\textit{[White Leghorn ♂ × Black Minorca ♀] ♂}}{\textit{Black Minorca ♀}}\right\}$ × *Black Minorca* ♀. Nature of mating: *CCBbffii* × *CCbbFfii*. (For discussion, see p. 195).

In case the barred, cross-bred cockerel, 325 B, possessed the barred character in heterozygous condition (as represented in the zygotic formula *CCffBbii*) it is to be expected that, when mated with pure Black Minorcas, one-half of his progeny would be barred. In the season of 1912 this mating was made with the results presented in Table 11.

TABLE 11.—Showing the results obtained from the cross indicated above.

MATING NO.	♂	♀♀	Total progeny.	BLACK.			BARRED.		
				♂	♀	?	♂	♀	?
472	325 B	184 A	13	4	2	0	4	3	0
473	325 B	34 A, B	53	12	13	3	9	12	4
Actual totals			66	16	15	3	13	15	4
Expected totals				16½	16½	....	16½	16½	....

The results of this cross demonstrate that the mating of the barred ♂, 325 B, with the pure-bred Black Minorca ♀♀ gave one-half barred and one-half black progeny; and that the barred and black birds were about equally divided between the sexes.

CASE 3d.—♂ $\left\{\dfrac{[\textit{White Leghorn } ♂ \times \textit{ Black Minorca } ♀]\ ♂}{\textit{Black Minorca } ♀}\right\} \times$ ♀ [*White Leghorn* ♂ × *Black Minorca* ♀]. Nature of mating: *CCBbffii* × *CCBbFfIi*. (For discussion, see p. 196).

In this instance, the barred cross-bred cockerel, 325 B, was bred to one of the ♀♀ which resulted from the first W. L. × B. M. cross. The results are presented in Table 12.

TABLE 12.—Showing the results of the mating indicated above.

MATING No.	♂	♀	Total progeny.	White.	BLACK.			BARRED.		
					♂	♀	?	♂	♀	?
474	325 B	200 D	34	17	1	1	2	7	2	4
Expected totals				17	C	4¼	...	8¼	4½	...

In Table 12 it is shown that one-half of the progeny of 325 B were dark and one-half light. Of the darks one-fourth were black and three-fourths barred.

CASE 3e.—♂ $\left\{\dfrac{[\textit{White Leghorn } ♂ \times \textit{ Black Minorca } ♀]\ ♂}{\textit{Black Minorca } ♀}\right\} \times$ ♀ $\left\{\dfrac{(\textit{White Leghorn } ♂ \times \textit{ Black Minorca } ♀)\ ♂}{\textit{Black Minorca } ♀}\right\}$ Nature of mating: *CCBbffii* × *CCbbFfii*, black, and *CCbbFfIi*, white, or *CCBbFfIi*, white. (For discussion, see p. 198).

In this case the barred cross-bred ♂, 325 B, was mated with two of his sisters, 325 A and 325 E. Female 325 A was clear black with blue-black beak and shanks and a slight green tinge to the plumage. Female 325 E was a white bird with light shanks and beak. The results of these matings are given in Table 13.

TABLE 13.—Showing the results of the crosses indicated above.

MATING NO.	♂	♀♀	Total progeny.	White.	BLACK.			BARRED.		
					♂	♀	?	♂	♀	?
470.........	325 B	325 A (black)	43	0	6	8	4	10	12	3
			Expected..	0	10¾	10¾	...	10¾	10¾	...
				Totals.	21½			21½		
471.........	325 B	325 E (white)	50	25	2	6	5	5	4	3
			Expected*.	25	6¼	6¼	...	6¼	6¼	...
				Totals.	12½			12½		

*Provided the zygotic constitution of the ♀ 325 E is CCbbFfIi.

From the data presented in Table 13 it is apparent that in the mating of 325 B with his black sister, 325 A, there was a tendency to produce equal numbers of black and barred progeny; and that the sex-ratio between these groups approximated 1 : 1.

In the mating of 325 B with his white sister, 325 E, half the progeny were white, while the other half included both black and barred birds in equal numbers and equally divided between the sexes.

CASE 3f.—♂ $\left\{\frac{\textit{(White Leghorn ♂} \times \textit{Black Minorca ♀) ♂}}{\textit{Black Minorca ♀}}\right\} \times$ *Black Java* ♀. Nature of mating: *CCBbffii* × *CCbbFfii*. (For discussion, see Case 5, p. 203).

Among the self-colored birds with which the barred cross-bred ♂ 325 B, was mated during the season of 1912 were the Black Java ♀♀ 335 C and F. The results of this mating are given in Table 14.

TABLE 14.—Showing the results of the mating indicated above.

MATING NO.	♂	♀♀	Total progeny.	BLACK.		BARRED.		
				♂	♀	♂	♀	?
477	325 B	335 C, F	52	11	16	10	14	1
Expected totals				13	13	13	13	....
Expected grand totals				26		26		

From the data presented in Table 14 it is clear that one-half of the progeny from this cross were black and one-half were barred; and that the black and the barred birds were about equally divided between the sexes. Similar results were obtained from mating the cross-bred ♂, 325 B, with Black Hamburg ♀♀. One of the ♂♂, 477 V, resulting from the Black Java cross, was mated in 1913 with a pen of barred ♀♀. This mating is considered in Case 5, p. 203.

CASE 4.—*White Leghorn* ♂ × *Black Java* ♀. Nature of mating: *CCBBffII* × *CCbbFfii*. (For discussion, see p. 186).

In other series of crosses bred in 1911, 1912 and 1913, the W. L. ♂, 193 A, used in the previous experiments, was mated with several B. J. ♀♀.

> *Black Java* ♀, *187 A:* Weight 7⅞ lbs., good form but slightly lacking in breast; beak black shading into yellow at base; eyes hazel; ear-lobes are three-fourths white; wattles red; small amount of purple barring on feathers of neck, wing coverts and tail coverts; primaries, secondaries and main tail feathers are dull black; under-color dark slate; shanks and feet yellow. The other Black Java ♀♀, 188 A, 230 A and 231 A, resembled the bird described above in all important points.

The result of this series of matings shows that as in earlier cases the white of the W. L. was dominant over the black of the Java; further, that as in other crosses, birds possessing a few barred feathers appeared in F$_1$. Of these birds two were ♂♂ in which the barred pattern appeared in the coverts or saddle feathers.

CASE 4a.—[*White Leghorn* ♂ × *Black Java* ♀] ♂ × [*White Leghorn* ♂ × *Black Java* ♀] ♀. Nature of mating: *CcBbffIi* × *CcBbFfIi*. (For discussion, see p. 193).

In the season of 1912 the cross-bred ♂ 25 C was mated with cross-bred ♀♀ of similar constitution. The cockerel was a solid white bird except for one feather in the middle of the back which showed barring on one-half. Of the ♀♀ used, 25 B showed at the age of one month slight barring in the right secondary coverts and in two secondaries. At the age of five months the barring had disappeared. Female 25 I showed a few dark saddle feathers but no barring. Female 203 B was a pure white bird.

TABLE 15.—Showing the results in F$_2$ of the White Leghorn × Black Java cross-breds (1912 series).

MATING NO.	♂	♀♀	Total progeny.	White.	BLACK.			BARRED.		
					♂	♀	?	♂	♀	?
481	25 C	25 B	33	26	0	1	0	2	1	3
482	25 C	25 I	38	27	0	3	0	5	2	1
483	25 C	203 B	44	38	0	2	1	1	2	0
Actual totals			115	91	0	6	1	8	5	4
Expected totals				86$\frac{4}{16}$	0	7$\frac{3}{16}$	...	14$\frac{6}{16}$	7$\frac{3}{16}$	...
Expected grand totals			....	86$\frac{4}{16}$	7$\frac{3}{16}$			21$\frac{9}{16}$		

In 1912 other crosses between W. L. and B. J. stock were made. These involved the use of W. L. ♂, 1 A. As expected, the first generation, raised in 1912, was composed entirely of white birds. The results in F_2 (1913) are shown in Table 16.

TABLE 16.—Showing the results in F_2 from the mating of White Leghorn × Black Java cross-breds (1913 series).

MATING NO.	♂	♀♀	Total progeny.†	White.	Black.†	Barred.*
553	463 A	463 E, F, J	30	18	3	9
554	463 A	464 K, N, Q	47	37	2	8
Actual totals	......	....	77	55	5	17
Expected totals	......	....	....	$57\frac{12}{16}$	$4\frac{13}{16}$	$14\frac{7}{16}$

*The sex of the black and the barred birds could not be ascertained in time to report in this publication.

†Over 3 weeks old when described.

The data presented in Table 16 indicate that in F_2 of the cross under discussion, white, barred and black birds appeared in the ratio 55 : 17 : 5.

CASE 5.—♂ { { *(White Leghorn ♂ × Black Minorca ♀) ♂* / *Black Minorca ♀* } ♂ / *♀ Black Java* } × *Cross-bred ♀♀, heterozygous for barring.* Nature of mating: *CCBbffii* × *CCBbFfii.* (For discussion, see p. 203).

Male 477 V was a fairly well-barred bird but with dark under-color. The general tone had a brownish tinge. The ♀♀ mated with him had the ancestry given below:

461 E.—♂ *[Wh. Leghorn ♂ × Blk. Hamburg ♀]* / ♀ { *(Wh. Leghorn ♂ × Blk. Hamburg ♀) ♂* / *(Wh. Leghorn ♂ × Blk. Hamb. ♀) ♀* }

343 B, E.—Out of mating given in Case 3e; from black ♀.

344 B.—Out of mating given in Case 3e; from white ♀.

$$\left.\begin{array}{l}\text{472 E.}\\ \\ \text{473 F.}\end{array}\right\}\ \frac{♂\left\{\dfrac{\textit{(White Leghorn ♂ × Black Minorca ♀) ♂}}{\textit{Black Minorca ♀}}\right\}}{\textit{♀ Black Minorca.}}$$

$$\text{474 G.—}\ \frac{♂\left\{\dfrac{\textit{(White Leghorn ♂ × Black Minorca ♀) ♂}}{\textit{Black Minorca ♀}}\right\}}{\textit{♀ (White Leghorn ♂ × Black Minorca ♀)}}$$

$$\text{476 A.—}\ \frac{♂\left\{\dfrac{\textit{(White Leghorn ♂ × Black Minorca ♀) ♂}}{\textit{Black Minorca ♀}}\right\}}{\textit{♀ Black Hamburg}}$$

477 E, P, S.—Same ancestry as 477 V.

The results of these matings, which were made in the season of 1913, are presented in Table 17.

TABLE 17.—Showing the results obtained from the matings described above.

MATING NO.	PARENTS.		Total progeny.*	BLACK.†	BARRED.†
	♂	♀♀			
541	477 V	461 E	40	15	25
542	477 V	343 B	17	6	11
543	477 V	343 E	14	3	11
544	477 V	344 B	2	0	2
545	477 V	472 E	10	4	6
546	477 V	473 F	29	10	19
547	477 V	474 G	1	0	1
548	477 V	476 A	27	7	20
549	477 V	477 E	33	13	20
550	477 V	477 P	30	7	23
551	477 V	477 S	27	5	22
552	477 V	347 E	17	5	12
Actual totals			247	75	172
Expected totals			....	62	185

---

*Over 3 weeks old when described.

†The sex of the black and the barred birds could not be ascertained in time to report in this publication.

IV. General Discussion of Results.

The experimental data presented in the foregoing pages make it clear that a type of barred plumage-pattern has arisen in F_2 from the mating of white with black birds. First of all we may ask: Where did this barring, manifested in a few feathers of a small number of F_1 individuals but appearing as a fully developed barred pattern in a certain proportion of F_2 progeny, have its origin? As stated at the beginning of this paper it was tentatively assumed, when the present investigations were planned in 1909, that barring represented a heterozygous condition resulting from the crossing of light colored with dark colored birds. This tentative assumption was based on the fact that breeders* have commonly made the observation that the crossing of Blacks × Whites occasionally gave some birds with good barring. Thus the barred plumage-pattern was considered by some as a mosaic made up of black and white. It is now clear, however, that this view is not supported by any evidence supplied by the present investigations. In F_1, contrary to expectation, the degree of dominance of white in all the White Leghorn × Black crosses was so great that the presence of black pigment was usually manifested only as flecks on an otherwise pure white plumage, or, in a smaller number of cases, as a partly barred feather among the white. If the barred pattern were of the nature of a mosaic, it should appear most definitely in F_1; one would not be led especially to anticipate its appearance in F_2,—at least in a well developed condition. But as shown in all the tables giving data on the F_2 birds this is exactly where the most extended and most clear-cut barring did appear.

In contrast to the view outlined above, several other investigations† dealing with the type of barring found in Barred Plymouth Rocks have shown that this character as there found may behave in inheritance like a unit-character; it is separately heritable. In other words, birds that show this barred pattern may be assumed to possess the *factor* for barring; and without the presence of this factor in the zygote, barring cannot appear. Thus the outcome of the first season's breeding of black with white birds, when coupled with the evidence of the existence of a barring factor, *B*, supplied by other breeders, demanded a change in view regarding the origin of the barring in question; at least it required a consideration of the possibility that a *factor* for barring might be present in one of the parent breeds used in the experiments.

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*See Davenport (1906); Wright (1905); Hurst (1905).

†Goodale (1909); Pearl and Surface (1910).

If a factor for barring were present in any of the parent breeds it seemed probable that it did not exist in the black ♀♀, since experience has shown that the black pigment possessed by these birds would cause the barring factor to be revealed even if it existed in a heterozygous condition.* Hence it was assumed that it might be present in the W. L. ♂; and it became the aim of the investigation to test this point experimentally; furthermore to ascertain the behavior of this type of barring in F_2 and subsequent generations; also to produce, by the breeding of selected birds possessing the requisite gametic constitution, a barred breed, wholly distinct (at least with respect to the origin of the barred pattern) from the Barred Plymouth Rocks. To what extent these results have been accomplished will appear in the following pages.

First, however, it is desirable to consider in some detail the probable zygotic constitution of the black and white fowls concerned in the experiments, since the expression of the factor for barring is dependent as will be shown, upon the presence or absence of several other factors,—especially the factors for sex and for the inhibition of black pigmentation. We may therefore inquire, first, as to what factors, among those with which we are especially concerned, are present in the birds used in the matings already described.

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*For instance, it is well known that if pigment be added to the White Plymouth Rock, as a result of mating with black breeds, the barring will be revealed in F_1.

It seems probable that we have to deal with at least four different factors: (1) a factor for black pigmentation, C[*], (2) a factor for the inhibition of pigmentation, I; (3) a factor for sex (F, female; f, male); and (4) a factor for barring, B.

With reference to these factors, what then is the zygotic constitution of the black ♀♀? First, we can assume that they are homozygous for black pigmentation (CC)[*]; second, that they are homozygous for the absence of barring (bb); further, that they are homozygous for the absence of the inhibiting factor (ii) which factor, in the case of the W. L., as will appear, prevents the black pigment from showing. Finally, we will assume that they are heterozygous for the female sex (Ff). The zygotic formula of these birds could therefore be written $C_2b_2Ffi_2$.

Making use of these symbols we may now consider the zygotic formula for the W. L. ♂. The W. L. breed of fowls is usually regarded as a "pure" white variety, sometimes called the dominant white or D-white, since in matings with dark birds the white appears to dominate over black. But, if we regard the white plumage as an *absence of pigmentation* it is manifestly illogical to say that the absence of a character can be dominant over its presence. Therefore another explanation must be sought for the apparent dominance of white, and we may assume with Bateson and Punnett (*op. cit.*) that the dominance of white is due to the inhibiting factor I, which has the power to repress the manifestation of black pigment in the plumage; and this power is still present, although lessened, when I_2 is diluted to a heterozygous condition, *Ii*, as is the case in F_1 of the W. L. × Black cross-breds.

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[*] It appears from the work of Bateson and Punnett (1908) on the D-whites and the R-whites, that black pigmentation in poultry may not always be due to a single factor. There may be present a general factor for color, C, and in addition factors for special pigmentations, such as buff, red or black. The latter, as suggested by Davenport and others may be conceived of as partaking of the nature of an enzyme, which, as a result of its action upon C, produces the color in question. According to this view the presence of both factors would be required if the bird is to show pigmentation. For instance, with reference to the inheritance of color in birds possessing two kinds of pigments, we might need to consider three sorts of factors: the general color factor, C, and two special color factors, which working upon C, might produce, the one red, the other black pigment. The explanation of color-inheritance in poultry may eventually be found not even so simple as this; but it is apparent from results already attained that, as in the case of the inheritance of certain colors in the sweet pea, several factors may be involved. In the present case, however, we are concerned on the one hand, only with the presence of black pigmentation (or its potential possibility of appearance, other factors permitting) and, on the other hand, with the apparent absence of black. For this reason, and to avoid complexity, it will be sufficient for present considerations to assign to the black pigmentation a single factor, and this we will term C, with the understanding that in reality this character may be dependent upon the action of two factors instead of one. These might be compared with the factors which Davenport (1909) calls C and N; or to factors which Bateson and Punnett (1908) refer to as X and Y.

With our recognition of the fact that the W. L. ♂ carries inhibiting factors which repress the manifestation of black in the plumage of the progeny from matings with black breeds, the results of certain matings lead to the question whether the W. L. in its own somatic cells, possesses the elements of black pigmentation. Without now entering into a discussion of this point, which is considered in detail on a later page, it may be said that evidence derived from breeding experiments yet to be presented indicates that the W. L. ♂ carries in its germ cells the factor or factors for black pigmentation. This view will be found in harmony with the experimental results already given and with others to be mentioned subsequently.

Looking at the problem in this light the W. L. may be regarded not as an actually white bird, but as a black one in which an inhibiting factor prevents the black from appearing. We may then tentatively assume that the W. L. ♂ is homozygous for black pigmentation, and at the same time homozygous for the inhibiting factor. Of course, were the W. L. ♂ heterozygous for *C*, the visible results in F_1 would be approximately the same.

With respect to the factor for sex, assuming a Mendelian interpretation of this phenomenon, we may tentatively regard the W. L. ♂ as homozygous (*ff*) for the absence of the female sex factor, the ♀♀ as heterozygous (*Ff*) for F.

We come now to the relation of the W. L. ♂ to the factor for barring. If the W. L. carries barring at all, it might be assumed that it is either homozygous (*BB*) or heterozygous (*Bb*) for this character; and the theoretical results from crossing will vary with the possibility which we assume to hold true. In deciding this point we may take into consideration the probable manner of inheritance of barring in the W. L. breed provided this breed does actually carry, more or less regularly, the factor for the barred plumage pattern. Analogy with the Barred Plymouth Rocks permits the assumption that the W. L. ♂♂ are homozygous (BB) while the ♀♀ are heterozygous (Bb) for this character. This circumstance would maintain the barred pattern under conditions of equilibrium in both sexes in successive generations; and logically we cannot assume otherwise if our experimental birds belong to pure-bred stock. On this assumption, the complete zygotic formula for the W. L. ♂ would be $C_2B_2f_2I_2$, while that of the ♀ would be C_2BbFfI_2, since the ♀ is assumed to be heterozygous for both female sex and barring, and homozygous for the inhibiting factor. On the basis of these assumptions (which, it must be fully understood, are for the moment merely assumptions, used to frame a working hypothesis) we may now turn to a more detailed consideration of the special cases.

A. DISCUSSION OF THE SPECIAL CASES.

Cases 1, 2, 3 and 4.—On the basis of the assumed zygotic formulæ previously stated, what is the expected result of crossing the W. L. ♂ with the black ♀♀? The W. L. ♂ forms only one type of gamete,—CBfI, while the black ♀♀ form two types, CbFi and Cbfi. The mating may then be represented

$$\begin{array}{rl} \text{♂} & CBfI \cdot CBfI \times \\ \text{♀} & Cbfi \ \ \cdot CbFi = \\ \hline \text{♂ ♂} & C_2Bbf_2Ii, \text{ white} \\ \text{♀ ♀} & C_2BbFfIi, \text{ white} \end{array}$$

In other words, the first cross between the W. L. ♂ and the black ♀♀ gives birds that are all white and heterozygous for the barring factor and for I. It has been stated in the description of the experiments that a few F_1 birds put up one or two barred or partly barred feathers. This may be explained on the grounds that the dominance of the inhibiting factor, I, was not complete when, as in F_1, it existed in a heterozygous or simplex condition. Where a little black was permitted to show, there it filled out the pattern of a barred feather. When the black was inhibited to a still greater degree, the pigment appeared only as minute ticks on an otherwise white plumage. In this respect no difference was observed between ♂♂ and ♀♀. Davenport (1909) has reported that in certain crosses involving a W. L. Bantam ♂ and certain black ♀♀ the ticking was chiefly in the ♀♀.

We may now compare the results of the present matings with some similar cases reported by other investigators. First, among those who have used the W. L. may be mentioned Davenport (1906) who reports the following instances:

1. *W. L. (Bantam)* ♂ × *Dark Brahma* ♀. Result: 16 white, or white splashed; 5 black; 7 barred and 3 of the Brahma type. All of the blacks were ♀♀, while of the barred birds, 3 were ♂♂, 2 ♀♀ and 2 of unknown sex.
2. *W. L. (Bantam)* ♂ × *Black Cochin (Bantam)* ♀. Result: 10 white, 7 black and 7 barred.
3. *Single Comb W. L.* ♂ × *Houdan* ♀. Result: Of 41 individuals, all were white with traces of black.

In the following cases, Davenport mated various ♂♂ with White Leghorn ♀♀:

4. *Black-breasted Red Game Bantam* ♂ × *W. L. (Bantam)* ♀. Result: Among 24 individuals were 12 dark and several barred birds.
5. *Buff Cochin Bantam* ♂ × *W. L. (Bantam)* ♀. Result: Among 31 offspring were 9 white, 9 white and buff, 4 white and black, 2 white, black and buff, 4 black and buff, and 3 black. No barred birds were reported for this cross.
6. *R. C. Black Minorca* ♂ × *S. C. W. L.* ♀. Results: Of 83 birds, 74 were white and 9 were pigmented. Davenport states, however, that one of the Leghorns used (B) in this cross gave all the dark progeny, while the other two Leghorn ♀♀ (A and C) gave only white.

To the above cases in which the W. L. ♀ was used, Hurst (1905) adds the following cases:

7. *Houdan* ♂ × *W. L.* ♀. Results: 94 whites and 11 blacks. Of the blacks there were 6 pure blacks (♀♀) and 5 barred (♂♂).
8. *Black Hamburg* ♂ × *W. L.* ♀. Results: Of 57 individuals (in down-feathers) 49 were white and 8 were black.

Regarding the eight instances reported by Davenport and by Hurst, the following may be said:

Instance 1.—Davenport's W. L. Bantam ♂ was undoubtedly heterozygous for both *B* and *I*. The pure-bred W. L. ♂ must be regarded as homozygous for I. If the W. L. Bantam in question possessed the constitution C_2Bbf_2Ii, one would expect in F_1 equal numbers of dark and light birds; and each sort would be equally divided between the sexes. Of the dark birds, half should be barred and half non-barred. The actual and the expected results can be represented as follows:

RESULTS.	White.	Black.	Barred.	Brahma.
Actual..............................	16	5	7	3
Expected............................	15½	7¾	7¾	(?)

It is clear that, on this interpretation, there is close correspondence between the actual and expected in Davenport's first instance, second series (*l. c.*, p. 37), in which the ♂ parent was the W. L. Bantam.

Instance 2.—In this case, Davenport's results are explainable on the hypothesis made for Instance 1. If the constitution of the W. L. Bantam were C_2Bbf_2Ii, we should have the following ratios:

RESULTS.	Total.	White.	Barred.	Black.
Actual..............................	24	10	7	7
Expected............................	....	12	6	6

This explanation is also in accord with Davenport's results in mating the same W. L. Bantam ♂ with W. L. ♀♀ (Davenport's Nos. 127 and 128).

Instance 3.—The results in F_1 are in full accord with the present hypothesis. Apparently the W. L. ♂ was homozygous for I.

Instance 4.—If we assume that the W. L. Bantam was heterozygous for I and B, and that B is, in this case, a sex-limited character, we should expect to find, among 24 individuals, 12 white and 12 dark; of the latter, 6 would be black ♀♀ and 6 barred ♂♂. Actually Davenport obtained 12 whites, and 12 darks. Of the darks, some (actual numbers not given) were barred and these were all ♂♂. This explanation places Davenport's results in full accord with the present hypothesis.

Instance 5.—The results of this mating are consistent with the explanation furnished in this paper, and suggested in Davenport's report (*op. cit.*, p. 82). The only possible difference is one of interpretation, in that we may regard the W. L. Bantam as heterozygous for I, instead of "heterozygous in white" as indicated by Davenport.

Instance 6.—In the case of the ♀♀ A and C the results are as expected. Both birds were apparently homozygous for I. As Davenport states, "B's germ cells were probably mixed;" it was doubtless heterozygous for I.

Instance 7.—From the first cross mentioned by Hurst (*op. cit.*, p. 133) we should expect nothing but white birds. The fact that 6 blacks and 5 "cuckoos" were observed in F_1 demonstrates, as suspected by Hurst, the "mixed" nature of some of the stock. If, as was the case in Davenport's Instance 4, these impure W. L. ♀♀ were heterozygous for both I and B, then we would expect exactly the "curious" results obtained by Hurst. The heterozygous barring of the "mixed" ♀ or ♀♀ would be transmitted only to the ♂♂ while it is most improbable that the ♀♀ could derive barring from the Houdan ♂ [$C_2b_2f_2i_2$].

Instance 8.—In Hurst's Experiment 2 (*op. cit.*, p. 134) one would expect all the progeny to be white, or white flecked with black. The fact that black birds resulted from this cross indicates that some of the W. L. ♀♀ were not pure for I. The expected results are as in Instance 7, and the fact that Hurst reports no barred ♂♂ is doubtless due to the circumstance that the 8 blacks did not live long enough to develop barring. The sex-ratios are not reported.

In conclusion, it may be said regarding the above cases that the F_1 results of both Davenport's and Hurst's matings of W. L. stock with various black breeds are fully explainable on the hypothesis advanced above: that the W. L. ♂♂ are normally homozygous for *B* and *I*, while the ♀♀ are homozygous for *I* but heterozygous for *B*. Many of the birds used by both Davenport and Hurst were manifestly impure with respect to several factors.

CASES 1a, 2a, 3a and 4a.—What now happens when the F_1 cross-breds from any of the matings presented in Cases 1, 2 and 3 are mated among themselves? The white cross-bred ♂♂ as we have seen possess the zygotic constitution

$$C_2Bbf_2Ii$$

while the ♀ cross-breds are

$$C_2BbFfIi$$

The ♂ forms gametes,

$$CBfI \cdot CBfi \cdot CbfI \cdot Cbfi$$

Since the ♀ is heterozygous for three pairs of characters, eight sorts of gametes might be expected:

$$CBfI \cdot CBFI \cdot CbFI \cdot CBFi$$
$$CBfi \cdot CbfI \cdot CbFi \cdot Cbfi$$

But it has been pointed out on a previous page that in the case of the Barred Plymouth Rocks there is good reason for assuming that the factors *B* and *F* never pass together into the same gamete; that there is some sort of a repulsion between these factors. In the case of the Barred Plymouth Rocks this results in black, or at least non-barred ♀♀ when B. P. R. ♀♀ are crossed by the ♂ of a non-barred breed. Since we have observed in the data already presented a certain proportion of black ♀♀ are produced in F_2, we may tentatively assume that in the White × Black crosses being described there exists a similar incompatibility between the factors, *B* and *F*. It may therefore be supposed that of the 8 sorts of gametes that might be formed by the ♀ cross-bred (with the zygotic formula, $C_2BbFfIi$), there are actually formed only four; in other words, we may eliminate from consideration all possible gametic combinations containing both

B and F, together with their complementary gametic combinations. Looking at the matter in this light we have formed by the cross-bred ♀♀ only the following gametes:

$$CBfI \cdot CbFi \cdot CBfi \cdot CbFI$$

The mating between the F₁ ♂ and the F₁ ♀♀ may therefore be represented as follows:

$$\begin{array}{l} ♂\ CBfI \cdot Cbfi \cdot CBfi \cdot CbfI \times \\ ♀\ CBfI \cdot CbFi \cdot CBfi \cdot CbFI = \\ \hline \end{array}$$

$$♂♂ \left\{ \begin{array}{ll} C_2B_2f_2I_2 & (1), \text{ white} \\ C_2Bbf_2I_2 & (1), \text{ ``} \\ C_2Bbf_2Ii & (2), \text{ ``} \\ C_2B_2f_2Ii & (2), \text{ ``} \\ C_2Bbf_2i_2 & (1), \text{ barred} \\ C_2B_2f_2i_2 & (1), \text{ ``} \end{array} \right.$$

$$♀♀ \left\{ \begin{array}{ll} C_2BbFfI_2 & (1), \text{ white} \\ C_2b_2FfI_2 & (1), \text{ ``} \\ C_2BbFfIi & (2), \text{ ``} \\ C_2b_2FfIi & (2), \text{ ``} \\ C_2b_2Ffi_2 & (1), \text{ black} \\ C_2BbFfi_2 & (1), \text{ barred} \end{array} \right.$$

The data presented above may be summarized as follows:

CHARACTER.	♂	♀	Total.
White	6	6	12
Black	0	1	1
Barred	2	1	3
Totals	8	8	16

In other words, among every 16 birds in F₂ we may expect 12 whites, 3 barred and one black. The whites should be equally divided between the sexes; 2 of the three barred birds should be ♂♂ and all black birds should be ♀♀; moreover, one of the barred males should be homozygous for the barring factor while the other ♂ and the ♀ should be heterozygous. Other birds both ♂ and ♀ carry the barring factor but do not visibly manifest the barred pattern because they are either homozygous or heterozygous for *I*,—a circumstance which prevents the appearance of the pigment and therefore of the barring also.

Having thus outlined the expected results in the F_2 generation from White × Black crosses, provided the White Leghorn ♂ was actually homozygous for barring and actually possessed the inhibiting factor *I*, we may now attempt to ascertain to what extent these theoretical results agree with the experimental data and furnish an interpretation for them.

CASE 1a.—*White Leghorn × Black Hamburg, F_2.*—(Tables 3 and 4, pp. 167 and 168). First of all it is apparent that the ratio 3 white: one dark is closely realized among the 117 birds included in Table 3 and in the 137 birds comprising Table 4. In the 1911 series (Table 3) the actual results were 90 white : 27 dark, and the expected results 88 : 29. Whereas we should expect only 7 + blacks (all females) we actually have 12 (16 including the grays), including 9 ♀♀ and 3 in which the sex was not ascertained. In explanation of this discrepancy it may be said that in young chicks under 2 weeks of age, it is difficult to distinguish accurately the blacks from the barred. In case chicks die during the first week or two, all those which might later develop barring must be described as black. There can therefore be no doubt that several of the birds described as black would have become barred if they had lived. The only way seen at present to avoid this difficulty is to embody in the tables no chicks which die when less than 3 weeks of age. This plan was adhered to in the formulation of Table 4.

Regarding the barred birds, it is clear that more are called for (21+) than actually appeared (11); but as already explained, the deficiency would probably have been made up by addition of the individuals from the "black" column, if these had lived long enough to develop their barring. It is apparent, however, that the ratio of ♂♂ to ♀♀ is in the right sense.

Turning now to the results of similar matings presented in Table 4, it is apparent that the experimental results conform more closely to the expected. In this case all the chicks were over three weeks old when described. The obtained ratio of whites to blacks is 106 : 31, while the expected is 102 : 35. The actual ratio of black to barred birds was 7 : 24, while the expected was 8+ : 25+. As was to be expected no black ♂♂ appeared while the number of barred ♂♂ was approximately twice the number of the barred ♀♀ (14:6), the expected being 17+ : 8+.

It is thus clear that when only chicks over three weeks old are included in the tables the actual and the expected ratios find close agreement, and appear to demonstrate the correctness of the view that the ♂ W. L. is homozygous for the barred plumage pattern.

CASE 2a.—*White Leghorn* × *Black Spanish*, *F_2*.—(Tables 6, 7 and 8, pp. 171 and 172). The 1911 results presented in Table 6 show a predominance of whites and a deficiency of both black and barred birds. These matings were repeated in 1912 to ascertain whether the same defective ratios were present. Table 7 makes it appear that both the excess of whites and deficiency of dark are still apparent, although in the case of the progeny of 14 D, S and T* the experimental results are closer to the expected. What circumstance causes the defective ratios shown in the totals in Table 9, cannot at present be stated. In this instance, some unsuspected factor may be at work.

CASE 3a.—*White Leghorn* × *Black Minorca*, *F_2*.—(Table 9, p. 173). Although only a small number of individuals were raised from this mating, the experimental results, as in the case of W. L. × B. H., F_2, are seen to correspond well with the expected.

CASE 4a.—*White Leghorn* × *Black Java*, *F_2*.—(Tables 15, 16, p. 179, 180). There is seen in the 1912 cross-breds a slight deficiency in the white and in the barred birds. But the ratios have an approximate agreement and the sex-ratios are all in the expected sense. In Table 15, showing the F_2 results of the 1913 series, it appears that the experimental results come very close to the expected.

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*These ♀♀ were raised from the Black Spanish mothers of F_1 in the season of 1911.

CASE 3b.—(*White Leghorn* × *Black Minorca*) ♂ × *Black Minorca* ♀. (Table 10, p. 174). It has been shown in Table 10 that when the White Leghorn × Black Minorca F_1 ♂ was bred back to pure Black Minorca ♀♀, the offspring included white, black and barred birds. We may now submit this case to Mendelian analysis, making use of the same factors as those employed in the discussion of F_2. Assuming the zygotic formula of the F_1 cross-bred ♂ to be C_2Bbf_2Ii, and that of the black ♀ to be $C_2b_2Ffi_2$, the mating may be represented:

$$\begin{array}{l} \text{♂ } CBfI \cdot Cbfi \cdot CBfi \cdot CbfI \times \\ \underline{\text{♀ } CbFi \cdot Cbfi =} \end{array}$$

$$\text{♂♂} \left\{ \begin{array}{l} C_2Bbf_2Ii, \text{ white} \\ C_2b_2f_2i_2, \text{ black} \\ C_2Bbf_2i_2, \text{ barred} \\ C_2b_2f_2Ii, \text{ white} \end{array} \right.$$

$$\text{♀♀} \left\{ \begin{array}{l} C_2BbFfIi, \text{ white} \\ C_2b_2Ffi_2, \text{ black} \\ C_2BbFfi_2, \text{ barred} \\ C_2b_2FfIi, \text{ white} \end{array} \right.$$

Thus, according to the present hypothesis, there would appear in F_2, in every lot of 8 birds, the following types:

CHARACTER.	♂	♀	Total.
White	2	2	4
Black	1	1	2
Barred	1	1	2
Total	4	4	8

Now how do the observed results compare with the expected? In Table 10 (p. 174), have been presented the experimental results which should test the present theory. It is there shown that of 6 birds half were white and half dark; of the darks two were black and one was barred. The number of individuals described is too small to be of great value but it appears that the trend of the data is towards the verification of the hypothesis which has been assumed to cover these cases.

CASE 3c. ♂ $\left\{\frac{[\textit{White Leghorn}\ ♂ \times \textit{Black Minorca}\ ♀]\ ♂}{\textit{Black Minorca}\ ♀}\right\}$ × *Black Minorca* ♀.—(Table 11, p. 175). Under the heading of Case 3b (Table 10) it has been shown that the mating (W. L. × B. M.) ♂ $[C_2Bbf_2Ii]$ × Black Minorca ♀ $[C_2b_2Ffi_2]$ gives one-eighth ♂♂ that are heterozygous for barring and lack the black-inhibiting factor *I*. Using as a breeding unit a ♂ having the zygotic constitution $C_2Bbf_2i_2$, it should be possible, if the theoretical deductions are correct, to build up a group of barred ♀♀ possessing the barring originally derived from the W. L. ♂. The first step in this process would be to demonstrate that ♂ 325B actually was heterozygous for the barring factor, and would transmit this character to his offspring; then to produce heterozygous ♀♀, free from *I*, and a homozygous ♂ possessing the zygotic formula $C_2B_2f_2i_2$,—in other words, the constitution of the pure-bred B. P. R. ♂. To accomplish the first step mentioned above ♂ 325B was mated with a number of black ♀♀, including Black Minorcas. Since these fowls have the zygotic constitution $C_2b_2Ffi_2$, compatible with the absence of barring, and of the inhibiting factor, the cross should bring out a certain number of ♀♀ manifesting heterozygous barring. This has appeared to be the case. The mating as made may be represented as follows:

The ♂ 325B, $[C_2Bbf_2i_2]$ may be assumed to form gametes,

$$CBfi \cdot Cbfi$$

and the black ♀♀ to form gametes,

$$CbFi \cdot Cbfi.$$

Since both ♂ and ♀ are now homozygous for C and i, these symbols may be left out of the mating formulæ:

$$\begin{array}{l}
\text{♂}\ Bf \cdot bf \times \\
\text{♀}\ bF \cdot bf = \\
\hline
\text{♀}\ b_2Ff \text{ — black} \\
\text{♀}\ BbFf \text{ — barred} \\
\text{♂}\ b_2f_2 \text{ — black} \\
\text{♂}\ Bbf_2 \text{ — barred}
\end{array}$$

In other words, provided ♂ 325B was actually heterozygous for barring, this mating should give equal numbers of barred and black birds, equally divided between the sexes. When we compare with these theoretical deductions the experimental results presented in Table 11, p. 175, it is apparent that there is close correspondence. Similar results were obtained from mating of ♂ 325B with Black Java ♀♀ (Case 3f) and Black Hamburg ♀♀. These matings served to give a number of ♀♀ heterozygous for the barred plumage-pattern, and freed from the pigment-inhibiting factor; and these fowls as described in Case 5 were mated in the season of 1913 with ♂ 477V, a bird which showed better barring than 325B. The data on the results of these crosses are reported on p. 180.

CASE 3d.—♂ $\left\{\dfrac{(\textit{White Leghorn}\ \text{♂} \times \textit{Black Minorca}\ \text{♀})\ \text{♂}}{\textit{Black Minorca}\ \text{♀}}\right\} \times$ (*White Leghorn* ♂ × *Black Minorca* ♀) ♀.—(Table 12, p. 176). Another method of testing the heterozygous nature of ♂ 325B for the barring factor was to mate this bird with (W. L. × B. M.) F_1 ♀♀. These we assume are, themselves, heterozygous for the barring factor and have the zygotic constitution $C_2BbFfIi$, a formula compatible with barred plumage rendered obscure by the presence of inhibiting factor I. These birds form gametes

$$CbFi \cdot CbFI \cdot CBfI \cdot CBfi$$

In this case the presence of the inhibiting factor I, in a heterozygous condition, would interfere with the manifestation of the barred color-pattern in one-half the progeny which would therefore be white.

Among the other half, lacking the inhibiting factor, a part should be barred and the remainder black.

If we assume that ♂ 325B, having the constitution $C_2Bbf_2i_2$, forms gametes

$$CBfi \cdot Cbfi$$

and that the ♀♀ [$C_2BbFfIi$] form gametes

$$CBfi \cdot CBfI \cdot CbFi \cdot CbFI$$

the mating may be represented:

$$\begin{array}{l} \text{♂}\ CBfi \cdot Cbfi \times \\ \underline{\text{♀}\ CBfi \cdot CBfI \cdot Cbfi \cdot CbFI} \end{array}$$

$$\text{♂♂}\left\{\begin{array}{l} C_2B_2f_2Ii, \text{ white} \\ C_2Bbf_2Ii, \text{ white} \\ C_2B_2f_2i_2, \text{ barred} \\ C_2Bbf_2i_2, \text{ barred} \end{array}\right.$$

$$\text{♀♀}\left\{\begin{array}{l} C_2BbFfIi, \text{ white} \\ C_2b_2FfIi, \text{ white} \\ C_2b_2Ffi_2, \text{ black} \\ C_2BbFfi_2, \text{ barred} \end{array}\right.$$

The data presented above may be summarized as follows:

CHARACTER.	♂	♀	Total.
White	2	2	4
Black	0	1	1
Barred	2	1	3
Total	4	4	8

In other words, among every 8 birds resulting from this cross, we should expect to find 4 whites, one black and 3 barred. Of the 4 white, one should be homozygous and 2 heterozygous for barring;

and of the barred birds one ♂ should be homozygous, one heterozygous, and one ♀ heterozygous for this character.

The experimental data presented in Case 3c may now be compared with these theoretical results. In Table 12, it was demonstrated that of 34 birds raised 17 were white and 4 were black, while 13 were barred as shown in the following diagram:

CHARACTER.	♂	♀	?	TOTALS.	
				Actual.	Expected.
White	......	......	17	17	17
Black	1	1	2	4	4¼
Barred	7	2	4	13	12¾
Totals	8	3	23	34	34

It will thus be seen that the correspondence between the actual and the theoretical results is very close.

$$\text{CASE 3e.—♂}\left\{\frac{(\textit{White Leghorn ♂} \times \textit{Black Minorca ♀})\ \text{♂}}{\textit{Black Minorca ♀}}\right\}\times$$

$$\text{♀}\left\{\frac{(\textit{White Leghorn ♂} \times \textit{Black Minorca ♀})\ \text{♂}}{\textit{Black Minorca ♀}}\right\}\text{—(Table 13, p. 177).}$$

The experimental data presented under the head of Cases 3c and 3d made it apparent that ♂ 325B was actually heterozygous for the barring factor, and had the zygotic constitution, $C_2Bbf_2i_2$. The next step in the process of obtaining (from the 325 group) the barring factor in a pure, homozygous condition was to obtain a ♀ crossbred heterozygous for this character.

Under the heading of Case 3b it has been shown that from the mating (White Leghorn × Black Minorca) ♂ × Black Minorca ♀ there were produced, along with the barred ♂ 325B, black ♀♀ and white ♀♀. From the mating in question one of each sort lived to maturity, black ♀ 325A and white ♀ 325E. A consideration of the analysis presented on p. 177, made it seem probable that 325A did not possess the barring factor, its zygotic formula being $C_2b_2Ffi_2$. The white ♀ 325E, however, might have had the zygotic constitution $C_2BbFfIi$ (compatible with a barred plumage rendered obscure by the presence of I); or the constitution C_2b_2FfIi (compatible with the total absence of the barring factor). We may now consider the details of these two matings, with the aim of demonstrating the actual zygotic constitution of the black and the white female cross-breds mentioned above, both being full sisters of ♂ 325B.

First Instance.—*♂ 325B (barred) × ♀ 325A (black):* As indicated above, ♂ 325B [$C_2Bbf_2i_2$] may be considered to form gametes

$$CBfi \cdot Cbfi$$

while the black ♀ 325A (his sister) [$C_2b_2Ffi_2$], forms gametes

$$CbFi \cdot Cbfi$$

The mating would then be represented:

♀ $CbFi \cdot Cbfi$ ×
♂ $CBfi \cdot Cbfi$ =
♀ $C_2b_2Ffi_2$, black
♀ C_2BbFfi_2, barred
♂ $C_2b_2f_2i_2$, black
♂ $C_2Bbf_2i_2$, barred

In other words, among every four birds two would be black and two would be barred; and in each of these groups there would be one ♂ and one ♀. Each of the barred birds would be heterozygous for this character. The expectation may be represented as follows:

CHARACTER.	♂	♀	Total.
Black	1	1	2
Barred	1	1	2
Totals	2	2	4

When we compare these deductions with the results actually obtained in experiments as presented on p. 177, it is apparent that the experimental results come fairly close to the expected. Of 43 birds described when over 3 weeks old, 25 were barred and 18 were black; and in each group the sex-ratios were approximately 1 : 1.

Second Instance.—*♂ 325B (barred)* × *♀ 325E (white)*; *first possibility:* We may consider first the case in which ♀ 325E is assumed to have the zygotic formula $C_2BbFfIi$, compatible with heterozygous barring rendered obscure by heterozygous I. As before, ♂ 325B may be assumed to form gametes,

$$CBfi \cdot Cbfi$$

while the ♀ 325E, forms gametes,

$$CbFI \cdot CbFi \cdot CBfI \cdot CBfi$$

The mating would then be represented:

$$\begin{array}{l} \text{♀}\ CbFI \cdot CbFi \cdot CBfI \cdot CBfi \times \\ \text{♂}\ CBfi \cdot Cbfi = \\ \hline \end{array}$$

$$\text{♂♂} \left\{ \begin{array}{l} C_2Bbf_2Ii, \text{ white} \\ C_2B_2f_2Ii, \text{ white} \\ C_2Bbf_2i_2, \text{ barred} \\ C_2B_2f_2i_2, \text{ barred} \end{array} \right.$$

$$\text{♀♀} \left\{ \begin{array}{l} C_2b_2FfIi, \text{ white} \\ C_2BbFfIi, \text{ white} \\ C_2BbFfi_2, \text{ barred} \\ C_2b_2Ffi_2, \text{ black} \end{array} \right.$$

These data may be summarized as follows:

CHARACTER.	♂	♀	Totals.
Black	0	1	1
White	2	2	4
Barred	2	1	3
Totals	4	4	8

It is thus apparent that in the mating under consideration among every 8 birds we may expect to have 4 white and 4 dark. Of the whites, 2 will be ♂♂ and 2 ♀♀. Of the darks, one will be black and 3 barred; the black bird and one of the barred birds will be ♀♀. It appears that the expectation of producing a ♂ homozygous for barring would here be attained. One out of every 8 birds (or one among every 3 barred ♂♂) should be homozygous for B.

We may now compare with these theoretical data the results obtained in the actual cross. As shown in Table 13 (p. 177), among 50 birds, 25 were white and 25 dark. Of the darks, 13 were black and 12 were barred. According to expectation we should have among 48 progeny the same proportion of light and dark birds, but the barred should stand in proportion to the blacks as 18 to 6; and all the blacks should be ♀♀. It is at once apparent that these expectations are by no means fulfilled, and we may therefore turn to a consideration of the second possible interpretation involving a different zygotic constitution for ♀ 325E.

Second Instance.—*♂ 325B (barred)* × *♀ 325E (white); second possibility:* On p. 177 reference has been made to the fact that ♀ 325E, so far as appearance was concerned, might have been heterozygous for the barring factor or might lack it. In the previous instance the case has been considered in which the bird was assumed to be heterozygous for B. In the present instance we may consider the probable results of mating in case 325E lacked this factor but was heterozygous for I,—in other words, possessed the zygotic constitution C_2b_2FfIi. The ♂ 325B would form gametes as previously shown while the ♀ might be assumed to form gametes

$$CbFI \cdot CbFi \cdot CbfI \cdot Cbfi$$

The mating would then be represented:

♀ $CbFI \cdot CbFi \cdot CbfI \cdot Cbfi$ ×
♂ $CBfi \cdot Cbfi$ =

$$\text{♂♂} \left\{ \begin{array}{l} C_2b_2f_2Ii, \text{ white} \\ C_2Bbf_2Ii, \text{ white} \\ C_2Bbf_2i_2, \text{ barred} \\ C_2b_2f_2i_2, \text{ black} \end{array} \right.$$

$$♀♀\begin{cases} C_2b_2FfIi, \text{ white} \\ C_2BbFfIi, \text{ white} \\ C_2BbFfi_2, \text{ barred} \\ C_2b_2Ffi_2, \text{ black} \end{cases}$$

These data may be summarized as follows:

CHARACTER.	♂	♀	Totals.
Black	1	1	2
White	2	2	4
Barred	1	1	2
Totals	4	4	8

From this it appears that among every 8 birds resulting from such a cross as that being considered we should expect to have 4 whites and 4 darks. Of the white birds 2 would be ♂♂ and 2 ♀♀. Of the dark birds 2 would be barred and 2 black, each group being equally divided between the sexes.

We may now compare with these data the results obtained in the cross 325B × 325E presented on p. 177, and attempt to decide regarding the actual zygotic constitution of 325E. The actual and expected results were as follows:

CHARACTER.	♂	♀	Sex. (?)	Totals.	Expected.
White	?	?	......	25	25
Black	2	6	5	13	12½
Barred	5	4	3	12	12½
Totals	......	......	......	50	50

It is at once apparent that there is close relation between the actual and the expected results in these cases, thus verifying the constitution of 325E as C_2b_2FfIi. It is therefore clear that neither 325A nor 325E could be used in further matings to produce a barred strain. This purpose was served, however, by the barred ♀♀, daughters of 325B, secured in the 1912 matings from the black mothers. These were mated in 1913, not with 325B, but with one of his sons, 477V, a bird which possessed a somewhat clearer pattern, and was chosen as one which might be homozygous for barring. The details of these crosses are as follows:

$$\text{CASE 5.—}\text{♂}\left\{\frac{\left\{\dfrac{(\textit{White Leghorn} \times \textit{Black Minorca})\ \text{♂}}{\textit{Black Minorca}\ \text{♀}}\right\}\text{♂}}{\text{♀}\ \textit{Black Java}}\right\} \times \textit{Cross-}$$

bred ♀♀, *heterozygous for barring* (Table 16, p. 177). Since the ♂ 477V and the barred ♀♀ are homozygous for both C and i, these symbols now may conveniently be left out of the mating formulæ, which may be given as follows:

The zygotic constitution of the ♂ 477V is

$$Bbf_2$$

forming gametes

$$Bf \cdot bf$$

The constitution of the ♀♀ is

$$BbFf$$

forming gametes

$$bF \cdot Bf$$

The mating may therefore be represented:

$$\begin{array}{l} \text{♀}\ Bf \quad bF \times \\ \underline{\text{♂}\ Bf \quad bf =} \\ \text{♂}\ Bbf_2\text{, barred} \\ \text{♂}\ B_2f_2\text{, barred} \\ \text{♀}\ b_2Ff\text{, black} \\ \text{♀}\ BbFf\text{, barred} \end{array}$$

These expected results may be summarized, and compared with the actual results, as shown below:

CHARACTER.	Expected ♂♂	Expected ♀♀	Expected totals.	Actual totals.
Black........................	0	1	1	74
Barred........................	2	1	3	175
Totals.....................	2	2	4	249

When the actual results (Table 17, p. 181) are compared with the expected it is clear that there is a close agreement. At the time this paper goes to press, it is impossible because of the immaturity of the stock to ascertain the sex-ratios and their relation to barring. It may be stated, however, that the 1913 progeny undoubtedly contains the expected proportion of ♂♂ homozygous for barring. It already appears possible to predict which these birds are by means of their lighter color. In this young stock there have already appeared birds which possess a much better grade of barring than any observed in the earlier stages of the investigation. To what extent selection for two or three years may be effective in further improving the character of the barred pattern remains of course to be ascertained. Suffice it to say at present that the mating described in Case 5 has finally yielded the expected ♂♂ homozygous, and ♀♀ heterozygous, for the barring factor; and these birds will now be used as selection= material for further improvement of the character under discussion.

B. DISCUSSION OF ADDITIONAL DATA NOT INCLUDED IN THE FOREGOING CASES.

During the course of these investigations a few other matings bearing upon the constitution of the White Leghorn have been made. These may be discussed briefly at this time, although the detailed results must await further breeding. These data relate to (1) the constitution of the W. L. ♀ with reference to the factor I; (2) the presence of factor C, or other factors for black pigmentation, in the W. L. ♂; (3) the possible identity between the factor I in the W. L. and Bateson and Punnett's factor I, of the Brown Leghorn,—an inhibitor of the Silky type of mesodermal pigmentation in crosses between the B. L. and W. S.; (4) the possible occurrence of barring in other breeds of fowl possessing the "R-white." These points may be taken up in the order of their presentation.

1.—*The constitution of the White Leghorn ♀♀ with respect to factor I.*—In order to throw light on this point crosses were made during the season of 1913 between the B. H. ♂ and W. L. ♀♀, these being the reciprocal of crosses mentioned earlier in this paper. F_1 gave only white birds, thus indicating the homozygous nature of the W. L. ♀♀ for the inhibiting factor. This result was naturally expected.

2.—*The factor for black pigmentation in the W. L. ♂.*—It has been assumed in this study that the W. L. ♂ is essentially a black bird in which the pigmentation is obscured by the action of the inhibiting factor I. It is now necessary to present the data upon which this assumption is based. First it may be said that this assumption regarding the zygotic constitution of the W. L. is in harmony with the majority of the experimental results already presented. To assume that the W. L. ♂ lacks the factor for black pigmentation is not in agreement with the results observed. But it has seemed possible to throw light upon this matter by other means. If the W. L. ♂ were mated with an R-white, such as the White Plymouth Rock, F_2 should yield some pigmented birds in which the factors I and C had become separated from each other. We may tentatively regard the zygotic constitution of the W. P. R. ♀ as c_2BbFfi_2 forming gametes

$$cBfi \cdot cbFi$$

The mating would then be represented:

$$\begin{array}{l} ♂\ CBfI \cdot CBfI \times \\ \underline{♀\ cBfi \cdot cbFi =} \\ ♀\ CcBbFfIi \text{ — white} \\ ♂\ CcB_2f_2Ii \text{ — white} \end{array}$$

In an actual mating of this sort, of 63 F_1 individuals all were white. Of this number, however, 5 showed one or more barred feathers. Except in the case of one ♀ the sex of these birds was not ascertained. Many of the F_1 generation, as chicks, showed patches of black down feathers, but when the birds had matured all barred feathers had disappeared and both sexes were pure white except for occasional black ticks. It is thus evident that, even in F_1, *pigment appeared from some source*, although the parent breeds were in appearance pure white. This result is explainable on the ground of the dilution of the *II* of the W. L. to *Ii* in the cross-breds. Better evidence is however, to be derived from observations on the F_2 individuals.

In obtaining the F_2, cross-bred ♂ 463A employed, was an almost white bird, and may be assumed to form gametes of four sorts, as follows:

$$CBfI \cdot CBfi \cdot cBfI \cdot cBfi$$

while the cross-bred ♀♀ (463 E, F, J; 464 K, I, N, Q) may be assumed to form gametes of eight sorts:

$$CBfI \cdot CBfi \cdot cBfI \cdot cBfi$$
$$CbFI \cdot CbFi \cdot cbFI \cdot cbFi$$

The mating may be represented as follows:

$$\text{♀}\ CBfI \cdot CBfi \cdot cBfI \cdot cBfi \cdot CbFI \cdot CbFi \cdot cbFI \cdot cbFi \times$$
$$\text{♂}\ CBfI \cdot CBfi \cdot cBfI \cdot cBfi =$$

$$\text{♀♀} \left\{ \begin{array}{l} C_2BbFfI_2\ (1),\ \text{white} \\ C_2BbFfIi\ (2),\ \text{white} \\ CcBbFfI_2\ (2),\ \text{white} \\ CcBbFfIi\ (4),\ \text{white} \\ c_2BbFfI_2\ (1),\ \text{white} \\ c_2BbFfIi\ (2),\ \text{white} \\ c_2BbFfi_2\ (1),\ \text{white} \\ C_2BbFfi_2\ (1),\ \text{barred} \\ CcBbFfi_2\ (2),\ \text{barred} \end{array} \right.$$

$$
♀♀\begin{cases}
C_2B_2f_2I_2 \text{ (1), white} \\
C_2B_2f_2Ii \text{ (2), white} \\
CcB_2f_2I_2 \text{ (2), white} \\
CcB_2f_2Ii \text{ (4), white} \\
c_2B_2f_2I_2 \text{ (1), white} \\
c_2B_2f_2Ii \text{ (2), white} \\
c_2B_2f_2i_2 \text{ (1), white} \\
C_2B_2f_2i_2 \text{ (1), barred} \\
CcB_2f_2i_2 \text{ (2), barred}
\end{cases}
$$

The data given above may be summarized in the following table:

CHARACTER.	♂	♀	Total.
White	13	13	26
Barred	3	3	6
Total	16	16	32

It is thus apparent that among every 32 F_2 individuals, one would expect to obtain 6 barred birds, equally divided between the sexes. The results may now be compared with the expectations as follows:

CHARACTER.	Actual.	Expected.
Barred	11	$11\frac{7}{16}$
White	50	$49\frac{9}{16}$
Totals	61	61

These results appear to justify the view that either the W. L. ♂ or the W. P. R. ♀♀ must be homozygous for the factor for black pigmentation. Since we know that whenever black pigmentation is added to the barred pattern possessed as a cryptomere by the W. P. R. breed, the barring appears, we are forced to the conclusion that this breed does not normally carry this factor for black pigmentation but that the character lies dormant in the W. L. stock reappearing when it is freed from its inhibitor I. The fact that no black individuals, ♂♂ or ♀♀, but only barred (and white) birds arose from this cross in F_2 is additional proof of the homozygous condition of the W. L. ♂ with respect to the factor for barred plumage pattern.

There may be, however, one other possible explanation of the appearance of black-pigmented feathers in F_1 birds and a certain proportion (6 in 32) of barred individuals in F_2. It is conceivable that the W. L. ♂ and the W. P. R. ♀ each contain one of the factors whose fusion is necessary for the full manifestation of black pigmentation. Bateson and Punnett (*op. cit.*) have described a case in which the mating together of two R-whites produced progeny all of which were dark colored. These factors may be designated X and Y and it may be assumed that, while neither alone can determine black pigmentation, X and Y working together (*i. e.*, XY) are able to bring it about. In case the W. L. ♂ was homozygous for the factor X, and the W. P. R. ♀ homozygous for the factor Y, all the offspring would be XY,—compatible with black pigmentation. But upon the assumption that the W. L. ♂ is I_2, this pigment would not be manifested in the F_1 individuals. Making use of this hypothesis the W. L. ♂ would be $B_2f_2I_2X_2y_2$ forming gametes

$$BfIXy \cdot BfIXy$$

while the W. P. R. ♀♀, having the zygotic constitution $BbFfi_2x_2Y_2$, would form gametes

$$BfixY \cdot bFixY$$

The mating would then be expressed:

♂ $BfIXy \cdot BfIXy \times$
♀ $\underline{BfixY \cdot bFixY =}$
♂♂ $B_2f_2IiXxYy$, white
♀♀ $BbFfIiXxYy$, white

All of the F_1 individuals are heterozygous for I, X and Y. The presence of X and Y together would determine pigmentation, but this would be obscured by I, although in heterozygous condition. It is conceivable, however, that Ii might permit a small amount of black to appear in the early feathering of F_1; and this condition was actually found to occur as also pointed out by Goodale (1910). In this paper it has been shown to hold for F_1 in nearly all of the White × Black crosses.

In the production of F_2 of the cross under discussion, a ♂ F_1 white cross-bred $[B_2f_2IiXxYy]$ would form gametes of 8 sorts:

$BfIXY \cdot BfixY \cdot BfIXy \cdot BfixY$

$BfIxy \cdot BfiXY \cdot BfIxY \cdot BfiXy$

while F_1 cross-bred ♀ $[\mathrm{BbFfIiXxYy}]$ would form 16 kinds of gametes:

$BfIXY \cdot Bfixy \cdot BFIXY \cdot bFixy$

$BfIXy \cdot BfixY \cdot bFIXy \cdot bFixY$

$BfIxY \cdot BfiXY \cdot bFIxY \cdot bFiXY$

$BfIxy \cdot BfiXy \cdot bFIxy \cdot bFiXy$

This mating would give 128 individuals possessing 27 different zygotic constitutions as follows:

♂ COMBINATIONS.

$B_2f_2I_2X_2Y_2$ (1), white
$B_2f_2IiXxYy$ (8), white
$B_2f_2I_2X_2Yy$ (2), white
$B_2f_2IiXxY_2$ (4), white
$B_2f_2I_2XxYy$ (4), white
$B_2f_2IiX_2Y_2$ (2), white
$B_2f_2I_2XxY_2$ (2), white
$B_2f_2IiX_2Yy$ (4), white
$B_2f_2IiXxy_2$ (4), white
$B_2f_2I_2X_2y_2$ (1), white
$B_2f_2I_2Xxy_2$ (2), white
$B_2f_2IiX_2y_2$ (2), white
$B_2f_2Iix_2Yy$ (4), white
$B_2f_2Iix_2Y_2$ (2), white
$B_2f_2I_2x_2Yy$ (2), white
$B_2f_2I_2x_2Y_2$ (1), white
$B_2f_2Iix_2y_2$ (2), white
$B_2f_2I_2x_2y_2$ (1), white
$B_2f_2i_2x_2y_2$ (1), white
$B_2f_2i_2x_2Yy$ (2), white
$B_2f_2i_2X_2y_2$ (1), white
$B_2f_2i_2Xxy_2$ (2), white
$B_2f_2i_2x_2Y_2$ (1), white
$B_2f_2i_2XxYy$ (4), barred
$B_2f_2i_2XxY_2$ (2), barred
$B_2f_2i_2X_2Y_2$ (1), barred
$B_2f_2i_2X_2Yy$ (2), barred

Females, heterozygous for *B* and *F*, would be formed in the exactly same number and proportion as those indicated above for the ♂♂.

From this analysis it is apparent that among every 128 individuals 18 would be barred and 110 white, both the barred and the white birds being equally divided between the sexes as follows:

CHARACTER.	♂	♀	Total.
White	55	55	110
Barred	9	9	18
Total	64	64	128

In the following table, we may compare the actual with the expected results in F_2 as formulated upon the present hypothesis:

RESULTS.	White.	Barred.	Total.
Actual	50	11	61
Expected*	$49\frac{9}{16}$	$11\frac{7}{16}$	61
Expected†	$52\frac{27}{64}$	$8\frac{37}{64}$	61

*Provided the W. L. ♂ possesses the primary color factor, *C*, and the W. P. R. ♀♀ possess no contributing pigmentation factor whatever.

†Provided the W. L. ♂ possesses the "*X-factor*" and the W. P. R. ♀♀ the "*Y-factor*."

It is apparent from the summary presented above that on the basis of the single-factor hypothesis we should obtain 12 barred individuals in every 64, while on the double-factor hypothesis we should obtain only 9 in 64. The experimental results, comprising observations on 61 F_2 individuals, are slightly in favor of the former view. It must be borne in mind, however, that the difference between the two groups of expected results is slight, and final conclusions must be deferred until data are obtained on a larger number of F_2 birds than form the basis of present comparisons.

3.—*On the nature of the factor I of the White Leghorn fowl.*—Heretofore in this series of experiments the inhibiting factor has been observed only in its effect upon the factor (or factors) for black pigmentation of the feathers, and (still unpublished) of the beaks and shanks (epidermal pigmentation). Whether factor *I* has the power to inhibit in all cases other colors, such as buff and red, cannot be stated definitely at this time.* But one other point of interest has been raised with reference to the factor *I* as a result of reciprocal matings between the W. L. and W. S. breeds. The experimental data may be presented as follows:

From the cross, W. L. ♂ × W. S. ♀ all the progeny were white with the exception of a few minute black flecks and an occasional suffusion of buff on the breast or wing coverts. The ♂♂ and ♀♀ were exactly alike in appearance, not only with respect to the pigmentation of the feathers, beaks and shanks (epidermal), but also with respect to the typical mesodermal pigmentation of the W. S.

In the cross W. S. ♂ × W. L. ♀ the results were different: With respect to plumage pigmentation, both ♂♂ and ♀♀ were heavily splashed with black. The pigmentation was perhaps more apparent on the ♂ ♂. With respect to the Silky type of pigmentation, the heavily pigmented birds (eyes, beak, shanks, wattles, pleura, peritoneum, etc.), were invariably ♀♀. It is apparent that these results (so far as they relate to the inhibition of mesodermal pigmentation in the ♂♂), are in accord with the findings of Bateson and Punnett (*op. cit.*) from observation of reciprocal crosses between the Brown Leghorn and W. S.

The results obtained by the present writer make it appear that the W. L. ♀, as well as the B. L. ♀, possesses in heterozygous condition a factor for the inhibition of the Silky pigmentation; and that the inheritance of this inhibiting character is sex-limited, being transmitted from the ♀♀ to the ♂♂ only.

---

*It can now be stated, as a result of later work, that the red of the Rhode Island Red breed, is recessive to, and the buff of the Buff Leghorn and Buff Wyandotte dominant over, the white of the White Leghorn.

The differences in plumage-color (*i. e.*, heavily splashed F_1 birds from the W. S. ♂ × W. L. ♀ mating, etc.) are more difficult to explain and no attempt will be made to do so at this time.

In conclusion it may be merely pointed out that the factor which inhibits black pigmentation in the plumage corresponds with Bateson's and Punnett's inhibitor of Silky pigmentation in so far as its effect is observed only in W. S. ♂ × W. L. ♀ matings. But the factors seem to be distinct in that, while the inhibitor of Silky pigmentation is strictly sex-limited (preventing deep pigmentation in the F_1 ♂♂ from W. S. ♂ × B. L. ♀), the W. L. inhibitor of black in plumage does not appear to be sex-limited, since the F_1 from the W. S. ♂ × W. L. ♀ cross are also deeply splashed with black. It therefore appears that the White Leghorn breed of fowls possesses at least two distinct color-inhibiting factors,—one for the Silky type of pigmentation, the other for black pigmentation in the plumage. These points require further study.

4.—*The presence of the barred pattern in other breeds of fowl characterized by the R-white.* Outside of the White Plymouth Rocks, which as is well known possess barring as a cryptomere, only two other breeds characterized by the R-white have yet been tested for their possession of the barring factor. These are (1) the White Silky, (2) the White Minorca.

In the first of these crosses between the W. S. ♂ and B. H. ♀, of 9 individuals all were black; these manifested also the dark shanks, skin, and crest of the Silky. In F_2 the results were:

Black, including 2 blue	33
White	10
Game pattern, variously modified	9

Thus the expected 3:1 ratio appears among the black and the white birds with no observed manifestation of the barred pattern. No attempt will be made at this time to explain the appearance of the games.* It suffices the present purpose to state that the barred pattern did not appear in either F_1 or F_2 of the White Silky × Black Hamburg crosses.

In F_1 of the matings between a White Minorca ♂ and Black Hamburg ♀ all the progeny were black, the ♂♂ manifesting red saddle feathers. In F_2 of this cross (1913) the results were: black 78, white 27, the expected being: black 78¾, white 26¼. No barring appeared in either F_1 or F_2.

V. General Summary and Conclusions.

1.—In reviewing as a whole the results of the many crosses described in the foregoing pages it becomes apparent that, as was stated at the outset, the original aim of the investigation has not been realized. The main purpose was (in 1909) to produce, and then to "fix" the barred plumage pattern by means of suitable matings of white with dark birds, it being assumed tentatively that the barred plumage pattern might represent, as many breeders have supposed, a heterozygous condition of black and white,—a sort of a mosaic in the same feather. It is true that a part of the aim has been attained, in so far as a completely barred pattern was actually secured in F_2; and a pure strain of barred fowls has been built up from these barred F_2 individuals. But a consideration of the nature of this barring, together with a careful study of its manner of inheritance in the numerous crosses mentioned above, leaves no doubt that it could not have been produced *de novo* from the White × Black matings as first suspected, but that it had its origin in a *factor for barring* present in the gametes of the W. L. ♂. The evidence already presented indicates therefore that the W. L. ♂ is homozygous for this character B, while the ♀ is heterozygous. It also indicates that the W. L. ♂ carries a factor, C, or possibly other factors, for black pigmentation. This circumstance would naturally bring out the barred pattern were it not for the presence of an inhibiting fact, I, which represses the manifestation of black,—a factor for which the W. L. ♂ is also homozygous.

---

*This point, together with others which have arisen in the course of the investigations, will be considered in detail in a later publication.

2.—The zygotic constitution of the W. L. ♂ with respect to barring and the other factors concerned has thus been given provisionally as $C_2B_?f_2I_2$, and the ♀ as $C_2Bb_2FfI_2$. To what extent the W. L. stock of this country and Europe possesses this formula cannot now be definitely stated. All that may be said on this point at present is that the data presented in this paper are based on experiments which made use of some of the best W. L. stock obtainable.*

3.—The possible *origin* of the factor for barring in the W. L. has not been considered in these pages and it is probably useless to speculate on this point until we have more authoritative information relating to the foundation of this breed and to the manner of production of the various strains now scattered about the country. Among them all there may exist several variations in zygotic constitution.

4.—The result of the reciprocal crosses between the W. L. and W. S. indicates that ♂♂ of the former breed (as is also the case with the Brown Leghorn ♂) possess a factor which inhibits Silky pigmentation (mesodermal). The ♀♀ are heterozygous for this character, which is sex-limited in its inheritance. These "inhibiting factors," apparently possessed by the Leghorn breed of fowls as a whole, are of considerable interest and deserve further study. In the hands of the intelligent breeder, they suggest an effective instrument for controlling the manifestation of a variety of characters in poultry.

5.—Finally it may be said that the data reported in this paper explain certain curious results obtained by both Davenport and Hurst (*op. cit.*) with respect to barred progeny. They furthermore give an explanation for the interesting phenomenon occasionally observed by poultrymen,—the appearance of "cuckoo" progeny in F_1 or F_2 from supposedly non-barred parents; also for the otherwise unexplainable circumstance that barred ♀♀ have arisen from barred mothers in the case of crosses with W. L. ♂♂, it being now commonly assumed that the sex-limited character, barring, is inherited by ♀♀ from the ♂ only.

---

*Since the results presented in the body of this paper were secured, two other W. L. males have been tested, one coming from Professor James E. Rice of the Cornell Agricultural College and Experiment Station; the other from Professor Harry Lewis of the New Jersey Agricultural Experiment Station. Both were found to possess the barring factor as indicated by the appearance of barred feathers in the F_1 individuals.

As to the production of the barred pattern *de novo*, it has been indicated that barring was *not* obtained from two cases of matings between Blacks (Hamburg) and recessive Whites (Silky and Minorca). That the barred character can be produced, or "synthesized" from breeds not possessing the factor for barring now seems improbable; and we can agree with Correns (1905, p. 13) when he says: "Wo Mosaikbildung *als Regel* bei einem Bastard auftritt, war sie schon in einem der Eltern oder in beiden, aktiv oder latent, vorhanden."

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VII. Description of Plates.

PLATE I.

Figure 1. White Leghorn ♂, 193 A.
Figure 2. White Leghorn ♂, 1 A.

PLATE II.

Figure 3. White Leghorn × Black Hamburg, F_1 ♀, 10 I.
Figure 4. White Leghorn × Black Hamburg, F_1 ♂, 211 M_2.

PLATE III.

Figure 5. White Leghorn × Black Hamburg, F_2 ♀, 315 S.
Figure 6. Barred F_3 ♂, 477 V. (See text, p. 180).
Figure 7. Black Hamburg ♀, 5 A.
Figure 8. Barred F_2 ♂, 325 B. (See text, p. 175).

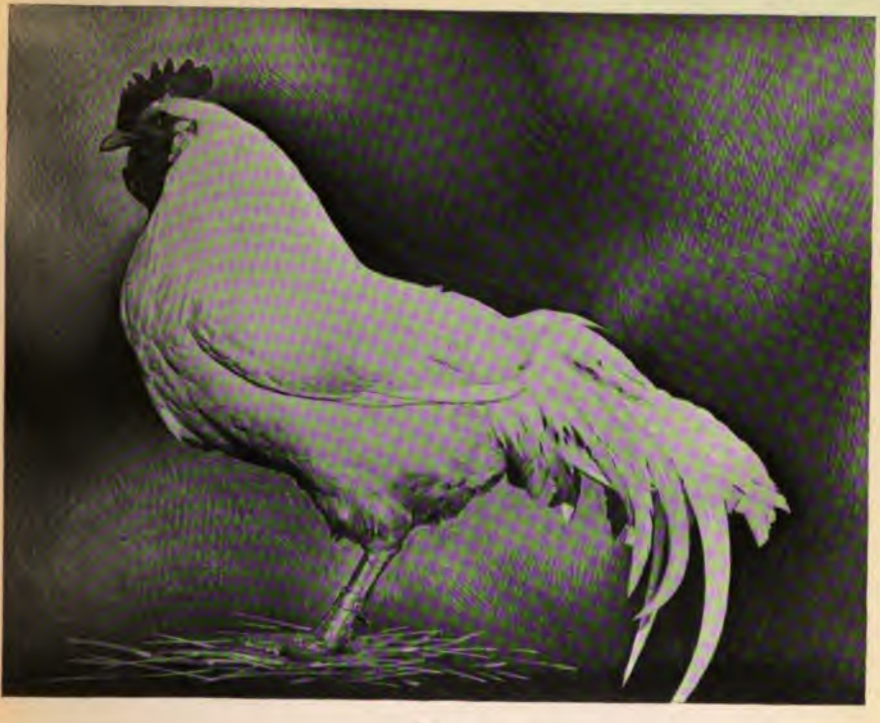

FIG. 1

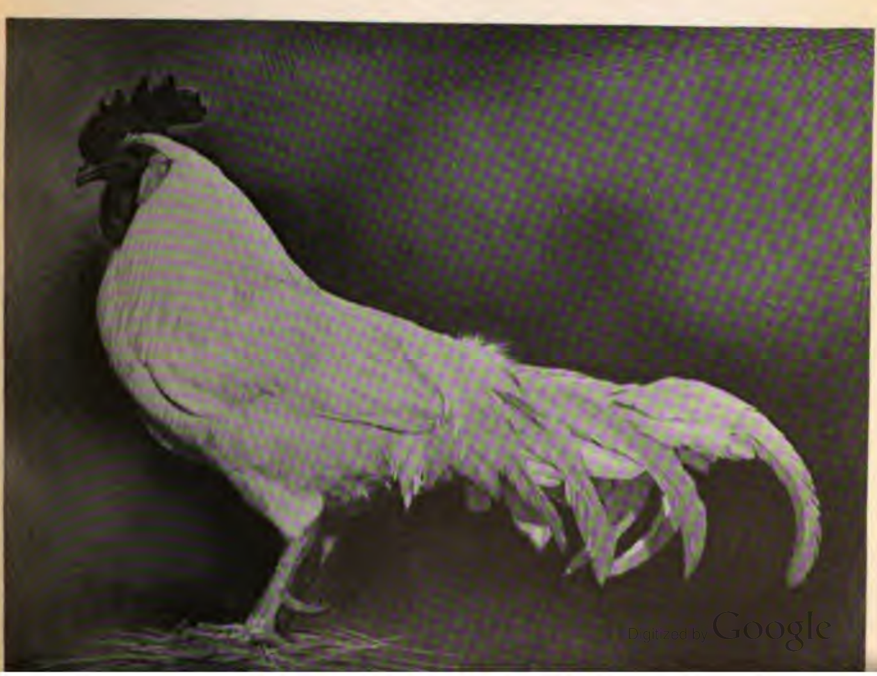

PLATE II.

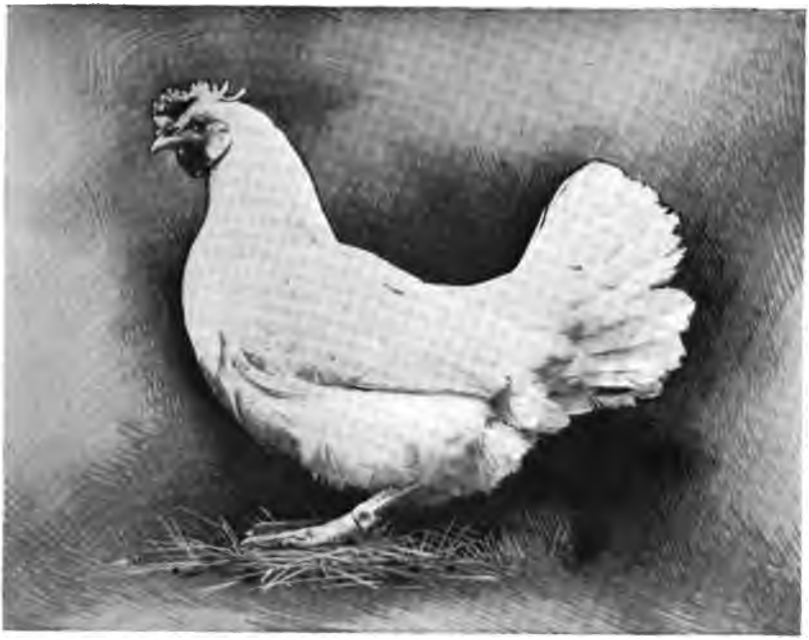

FIG. 3

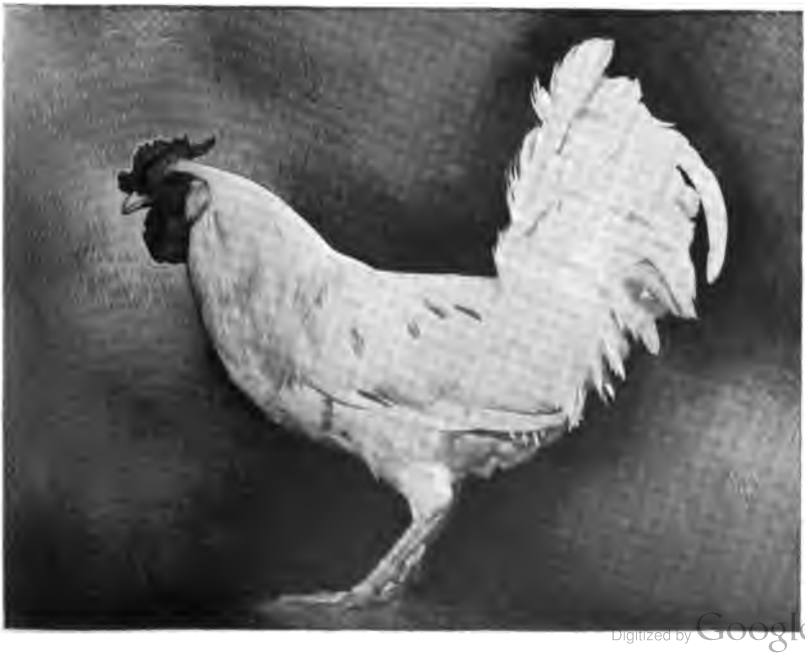

FIG. 4

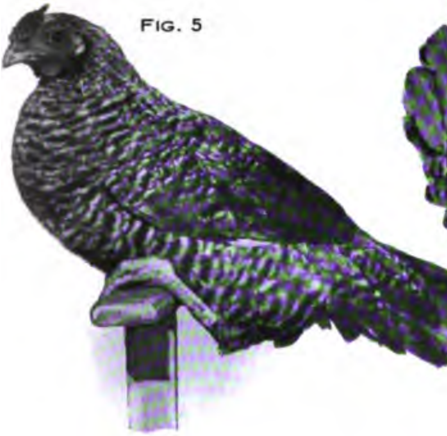

FIG. 5

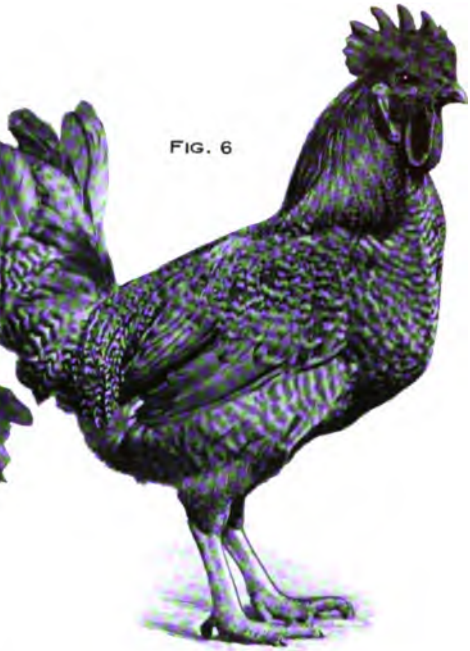

FIG. 6

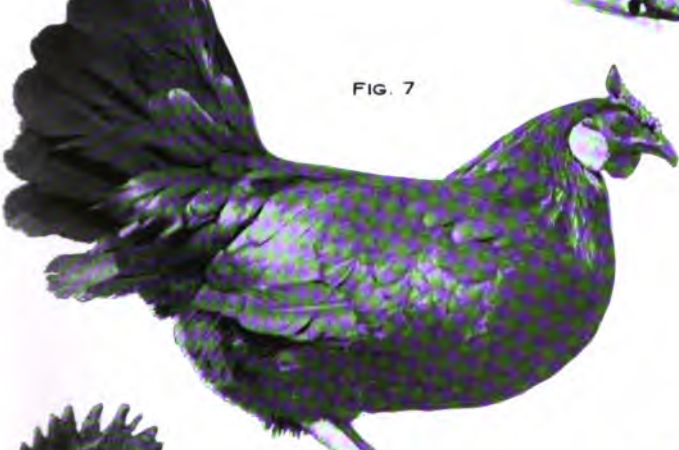

FIG. 7

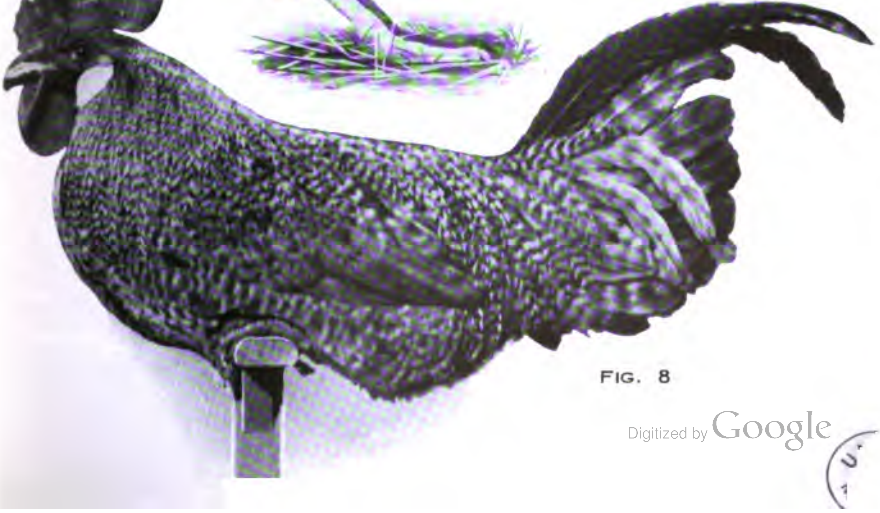

FIG. 8

THE AVAILABILITY OF THE NITROGEN OF COTTON-SEED MEAL AND BEEF SCRAP FOR CHICKS.

BULLETIN 156

Agricultural Experiment Station

OF THE

Rhode Island State College

KINGSTON, R. I., U. S. A., MARCH, 1914.

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AGRICULTURAL EXPERIMENT STATION OF THE RHODE ISLAND STATE COLLEGE.

BULLETIN 156, MARCH, 1914.

THE AVAILABILITY OF THE NITROGEN OF COTTON-SEED MEAL AND OF BEEF SCRAP FOR CHICKS.

BURT L. HARTWELL AND ROBERT A. LICHTENTHAELER.†

ABSTRACTS OF UNAVAILABLE BULLETINS OF THIS STATION, IN WHICH WERE RECORDED EARLIER EXPERIMENTS WITH PROTEIN CONCENTRATES.

It has become necessary, owing to the small number of copies on hand, to withdraw from general distribution those bulletins which contained accounts of feeding experiments with poultry, especially those with protein concentrates. On this account the present bulletin will not only contain the details of hitherto unpublished experiments, but also brief mention of the work published in two earlier bulletins, which are now unavailable.

Abstract of Bulletin 126, January 1908.

This bulletin was entitled "Feeding Experiments with Chickens, Cockerels and Turkeys."‡ The experiment with chickens was conducted to show the effect on the growth of the chicks of adding to basal feeds common to all the lots, cotton-seed meal, gluten feed or "granulated milk," each with and without additional bone constitutents, in comparison with the effect of an addition of animal meal, which of course naturally contained an abundance of bone. These protein concentrates were added to the basal feeds so as to furnish an equal percentage of protein, and the chickens were allowed to eat as much of the total feed as they desired in each case. Under these conditions the animal-meal ration produced by far the fastest growth. When the additional ash constituents (calcium carbonate and bone ash) were fed, the other protein concentrates gave much better results than when only the ash contained naturally in the feed was present. Other similar experiments were recorded in another bulletin to be abstracted.

---

*Contribution 203 from the Agricultural Experiment Station of the Rhode Island State College.

†The authors are indebted to Roy H. Waite and to the late D. E. Kolbe for their faithfulness and interest in caring for the chicks.

‡By J. Willard Bolté.

The experiment in fattening cockerels furnished data concerning the effects of an addition of 10 and of 20 per cent. of animal meal to a mixture composed of the following parts by weight, namely:

Sifted ground oats	1
Bolted corn meal	4
Middlings	2

when fed only in a trough, and also not only in the latter but in part by a cramming machine. Only four, thin fowls, six months of age and weighing about four pounds apiece were in each lot. They were confined in crates. During three weeks the average gain in pounds per cockerel was, when fed in the trough and by machine, .53 without animal meal, 1.09 with 10 per cent. of animal meal, and .63 with 20 per cent. of animal meal; the cost of feed per pound of gain being 19.8, 9.8 and 18 cents, respectively: when fed only in the trough the gain was .45 without animal meal; .76 with 10 per cent. added; and .62 with 20 per cent. added; the cost of feed per pound of gain being 19.9, 13.9 and 18.4 cents, respectively.

In order to secure an indication of the advisability of fattening turkeys in confinement instead of on the range, six lots composed of five turkeys each and weighing about twelve pounds per lot were fed in various ways during a period of ten days. The following summary, which is quoted from the bulletin, should be looked upon as only indicative:

"1. For a short feeding period there is not sufficient advantage in using a wet mash of mixed grains, at the prices quoted, to warrant the turkey fattener in adopting the ration.

"2. While the feeding of a mash partly in the trough and partly with a cramming machine gave the greatest average gains at the least cost for feed, the added outlay for labor over feeding corn on the range would make the latter method more profitable.

"3. Heavy feeding may hasten the development of the 'blackhead disease,' if it is already present in the system."

Abstract of Bulletin 145, April, 1911.

"Protein Concentrates for Winter Chickens" *was the title of the bulletin. In most of the experiments recorded the chicks were from two to four weeks old at the beginning and had reached the broiler stage when the experiments were terminated. In order to keep an accurate record of the amount of feed and ash constituents which they consumed, the chicks could be given no opportunity to wallow in dirt and fine litter. The floors of the pens were made of either concrete or boards, and covered with rye straw cut in pieces about four inches long. The data include, in pounds per ten chicks for each week, the feed consumed, the live weight and the gain in weight.

In most of the experiments the amounts of the concentrates compared were such that they supplied the same *proportion* of protein in the various rations. A considerable portion of the rations was purposely composed of the concentrates, in order that the effects of the latter might be more marked.

The principal results given in the bulletin can best be made available by the following quotation from the last three of its forty pages:

---

*By Burt L. Hartwell and W. F. Kirkpatrick.

"GENERAL CONSIDERATIONS.

". . . the chicks were generally allowed as much of the different rations as they would consume. Therefore the comparative merits of the concentrates have been judged principally with reference to the rapidity of growth, regardless of the amount of food consumed. Had the chicks in the lots under comparison been limited to the same amount of feed in all cases, so that no lot was given any more feed per chick than the one which was inclined to consume the least, the relative degree of efficiency between the concentrates would have been changed.

"When feeding winter chicks for market, the cost of feed is not the main item of expense; and a ration which will not produce rapid growth is not economical, even though its price is considerably lower than that of a ration which will be consumed in larger quantity and thus prepare the birds for market with the least expenditure for coal and care.

"Although the vegetable protein-concentrates have seemed to be inferior to the animal concentrates in the experiments which have been described herein, it should be recalled that they constituted quite a large part of the rations in order that most of the protein might be furnished by them, so that the effects of the concentrates might be marked. It would be a mistake to conclude that a concentrate which was not satisfactory when it supplied perhaps five-sevenths of all the protein, would not prove so when constituting a smaller proportion of the combined feeds.

"The experiments which have been described herein do not enable one to attribute the effect of a concentrate to any particular one of its ingredients. Although the concentrates which are being considered are secured primarily as sources of protein, they contain more or less of the non-nitrogenous ingredients of food, such as starch and fat. Even though the protein may constitute the principal food ingredient, and therefore be the main cause for the specific action of a concentrate when fed to chicks, which need so much protein, it must be understood that the results secured in these experiments should be attributed to the particular concentrate as a whole rather than solely to the kind of protein which it contains.

"SUMMARY.

"The experiments described in this bulletin were undertaken to compare the efficiency of various protein concentrates for promoting rapid growth of winter chicks.

"In the first two experiments was shown the extent of the beneficial effect of adding to rations composed of vegetable products such materials as bone ash and calcium carbonate, for the purpose of supplying the constituents of which the bones are composed. With rations composed largely of corn and wheat, together with linseed meal, gluten feed, or cotton-seed meal, as protein concentrates, the results were extremely unsatisfactory when the ingredients of bone were not added.

"Because of the differences in the amount of ash an attempt was made to provide an abundance of ash constituents in all cases where strict comparisons were made of the feeding value of the different concentrates. As compared with beef scrap and granulated milk, under such circumstances, the vegetable concentrates proved markedly inferior for rapid production of growth in the case of chicks which were allowed as much as they would consume of rations containing considerable proportions of the concentrates. This observation is based upon three comparisons with cotton-seed meal, two each with gluten feed and gluten meal, and two with linseed meal.

"Fresh beef scrap, and 'milk albumen' or granulated milk proved to be superior protein concentrates. Animal meal, which is less greasy and which on this account might appear dryer than beef scrap, was somewhat inferior to the latter. It is thought that in some instances it possibly contains objectionable ingredients, which are less likely to form a part of a beef scrap resulting from the manufacture of good tallow.

"The indications as furnished by only a single experiment were that bone ash is superior to finely ground phosphate rock as a source of calcium phosphate for chicks.

"In feeding chicks which weighed not less than 1.1 pounds, for two or three weeks with the purpose of finishing them for market, three experiments showed that no increased gain resulted from adding sugar to a given amount of feed; and it did not appear that the sugar caused a demand for a greater amount of feed.

"Two comparisons of rations containing different proportions of beef scrap resulted in greater gains in case of the larger admixture of beef scrap; that is, when it constituted about 26 per cent. instead of about 18 per cent. of a ration otherwise composed principally of corn meal and cracked corn."

INTRODUCTION TO THE HERETOFORE UNPUBLISHED EXPERIMENTS.

In case of the earlier work with protein concentrates, to which reference has been made, the chicks were allowed about all they would eat of the different rations. The concentrates were compared therefore largely with reference to their influence in promoting rapid growth, without limitations as to the amount of feed consumed.

In most of the experiments about to be described, however, the different lots in a given experiment received an equal amount of a basal ration, special additions being made to this common ration in case of different lots. It is evident that under these conditions the lot which consumed its feed least readily established a limit to the amount which the other lots could have, since all were to receive the same amount of the basal ration.

The attempt was made to supply in the basal ration such a large proportion of non-nitrogenous to nitrogenous ingredients that the influence exerted by the protein concentrates under experimentation would be attributable largely to their nitrogenous, rather than to their non-nitrogenous constituents.

In selecting a basal ration to contain all the possible necessary kinds of nitrogenous compounds, it was considered a desirable precaution to include a small quantity of a number of different protein concentrates, even of beef scrap and cotton-seed meal which were also to supplement the basal ration for the purpose of securing a strict comparison of the effect of an equal amount of nitrogen in them. A certain admixture of such material as bran and ground alfalfa was considered necessary to prevent stickiness and an undesirable mechanical condition in case of the food for any of the lots. Attention to these points led to the unavoidable addition of considerable protein (nitrogen times 6.25) to the basal ration even though corn and rice, on account of their low protein content, were used to make up the major part of the ration. The basal ration alone proved to be sufficiently low in protein, however, to allow only a very slow gain of the chicks.

The general plan of the experiments was similar to that usually followed in determining the availability for plant growth, of nitrogen in different nitrogenous manures. This requires the presence of optimum amounts of phosphorus, potassium and all nutrients other than nitrogen so that the growth shall be influenced only by the latter, which should be present in sub-optimum amounts in order that its full effect may be exerted. To conduct such an experiment properly, it is necessary to prove whether these supposed optimum and sub-optimum conditions really exist. This may be done by introducing groups to which larger applications are made.

Similarly, in the experiments with chicks, there were the "check" lots which received optimum amounts of ash and of non-nitrogenous feed constituents and a minimum amount of nitrogen; lots which received sub-optimum additions of nitrogen, the availability of which in the protein concentrates was to be determined; lots which received still more nitrogen for the purpose of showing whether the next smaller amount was really less than that required for most rapid growth; and lots to which more of the non-nitrogenous constituents were added so that an estimate could be made of the influence exerted by the similar constituents in the protein concentrates.

All of the experiments, except the first, were conducted in pens with concrete or board floors, and the litter consisted of clean, cut, rye straw or of sand so that the chicks could secure only such nourishment as was given to them in the foods. Much care was given to feed the latter so as to avoid loss. Such material as grit, oyster shells, charcoal, etc., was supplied. Prior to taking the final live weights, the feeds and water were withheld until the crops were empty.

In tabulating the feed consumed and the gain in weight on the basis of ten chicks, it was assumed, in case a chick had died, that it ate no food on the day of its death, and made no gain during the week in which it died. It is evident, therefore, that when there were deaths, the difference between the recorded live weight per ten chicks on two dates would not be expected necessarily to coincide with what is recorded as the gain per ten chicks during the intervening period. The general conduct of the experiments with the chicks were similar to that which was described in greater detail in Bulletin 145.

The principal part of the discussion referring to a number of experiments will not be given in connection with the individual experiments, but will be postponed until after the experimental details are recorded.

EXPERIMENT I. WITH CAPONS. COTTON—SEED MEAL VERSUS BEEF SCRAP IN RATIONS HAVING THE SAME NUTRITIVE RATIO AND AMOUNT OF NITROGEN; ALSO BEEF SCRAP IN A LARGER PROPORTION.

The White Wyandotte chicks which were eventually used in this experiment were allowed free range until July 20, 1909, when they were caponized, and confined to yards containing colony coops. Three equal lots of eighteen capons each were selected for the experiment which was begun on July 29 and continued until February 24, 1910, a period of about seven months. What little green growth there was originally in the yards had been destroyed, so that the only food which the capons could secure, aside from their rations, was that which they dug from the earth, or such insects as may have fallen from the shade trees.

All lots received the same amount of food per bird throughout the entire experiment, the quantity being regulated by the lot which was able to consume only the least amount.

Throughout the experiment the nutritive ratio* of the food for lots I and II was the same, whereas that of the food for lot III was narrower. On an equal nitrogen basis, cotton-seed meal was fed as the protein concentrate for lot I, in comparison with beef scrap as the protein concentrate for lot II: fifty per cent. more of the beef scrap was fed to lot III. The nutritive ratios were obtained by varying the proportions of wheat bran and corn meal used in the food for the different lots.

In adopting the rations for lots I and II an attempt was made to have them contain a smaller proportion of protein than was necessary for the most rapid growth, so that the increase in the proportion of protein given to lot III would result in a still more rapid development. To the extent that this object was attained, the relative effect of the cotton-seed meal and beef scrap fed to lots I and II, respectively, could be attributed mainly to the difference in the kind of protein, for the non-nitrogenous constituents in the food for these lots were more than equivalent to that in the food for lot III, and presumably above the proportion required for the capons. It is likely therefore that the growth was influenced mainly by the nitrogenous rather than by the non-nitrogenous constituents of the food.

The rations fed at different times during the experiment were as follows in parts per hundred weight:

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*Nutritive ratio as used in this bulletin is the ratio of the protein to the sum of the non-nitrogenous extract matter, and the fat multiplied by the factor 2.3. The more usual meaning has not been adopted because of the doubtful value of the fiber for chicks and the lack of information concerning the digestibility, for poultry, of the other constituents.

Lot I.	Aug. 5 to Sept. 8.	Sept. 9 to Oct. 6.	Oct. 7 to Nov. 10.	Nov. 11 to Feb. 24.
Ration:—				
Cotton-seed meal	15	10	12	9
Wheat bran	15	15	16	12
Corn meal	12	11	11	8
Bone ash	8	8	6	4
Cracked corn	42	47	49	60
Wheat	8	9	6	7
Approx. nutritive ratio	1:4.5	1:5.2	1:5.2	1:6.0
Lot II.				
Ration:—				
Beef scrap	12	8	9	6
Wheat bran	15	15	16	12
Corn meal	15	13	14	11
Bone ash	8	8	6	4
Cracked corn	42	47	49	60
Wheat	8	9	6	7
Approx. nutritive ratio	1:4.5	1:5.2	1:5.2	1:6.0
Lot III.				
Ration:—				
Beef scrap	19	11	12	9
Wheat bran	15	15	16	12
Corn meal	8	10	11	8
Bone ash	8	8	6	4
Cracked corn	42	47	49	60
Wheat	8	9	6	7
Approx. nutritive ratio	1:3.5	1:4.5	1:4.5	1:5.2

The wheat and cracked corn were fed as scratch feed. The remainder of the feed was given as a dry mash until the latter part of December, after which it was moistened.

One small capon belonging to lot III died on September 23, and on November 18 one crippled capon was removed from each of lots I and II, thereby reducing the number in each lot to seventeen. On December 23, one capon which was consuming very little food, was removed from lot I and to equalize the number of capons, for convenience in feeding, the lightest one from each of the other two lots was likewise removed. On January 7, one capon in lot III died and the lightest one in each of lots I and II was removed.

On account of a snow storm on January 20 the capons were closely confined to their coops for a time. This resulted in a decreased consumption of food and in such muddy pens that on February 3 the birds were removed to the incubator house. Since they did not eat so much food nor make so satisfactory gains there as when in the yards, the experiment was terminated on February 24, 1910.

The live weight, gain in weight, and feed consumed are recorded in Table I.

The rations for lot I, containing cotton-seed meal, and for lot II, containing beef scrap, had the same nutritive ratio and the same amount of nitrogen: the ration for lot III contained a larger amount of beef scrap and had a narrower nutritive ratio.

Table I. Record per Ten Capons Fed with Equal Amounts of Feed

1909.	Pounds of live weight.			Gain in live weight (lbs.) during the fortnight preceding the given dates.			Pounds of feed consumed during the fortnight preceding the given dates.
	Lot I.	Lot II.	Lot III.	Lot I.	Lot II.	Lot. III.	Lots I, II and III.
July 29	13.4	13.2	12.9	....	....	....	....
Aug. 12	18.3	18.5	18.9	4.9	5.3	6.0	20.1
Aug. 26	21.2	21.1	21.9	2.9	2.6	3.0	19.2
Sept. 9	23.6	23.8	24.3	2.4	2.7	2.4	21.4
Sept. 23	26.5	27.1	27.7	2.9	3.3	3.4	25.2
Oct. 7	30.9	31.9	34.4	4.4	4.8	6.7	28.1
Oct. 21	32.9	33.5	35.3	2.0	1.6	0.9	26.5
Nov. 4	39.5	41.1	41.1	6.6	7.6	5.8	37.5
Nov. 18	42.6	44.4	44.8	3.1	3.3	3.7	40.0
Dec. 2	43.2	45.3	48.2	0.6	0.9	3.4	37.1
Dec. 16	47.4	48.5	52.7	4.2	3.2	4.5	42.2
Dec. 30	56.6	59.5	61.4	9.2	11.0	8.7	47.6
1910.							
Jan. 13	61.7	65.5	68.3	5.1	6.0	6.9	54.4
Jan. 27	64.4	68.7	70.7	2.7	3.2	2.4	48.0
Feb. 10	66.7	71.7	73.3	2.3	3.0	2.6	50.0
Feb. 24	67.4	71.9	73.4	0.7	0.2	0.1	36.0
Total				54.0	58.7	60.5	533.3

The following data concerning the fifteen birds in each lot were secured at dressing time:

	Lot I.	Lot II.	Lot III.
Live weight of lot, lbs	101.1	107.8	110.1
Dressed weight of lot, lbs	92.3	97.3	100.4
Drawn weight of lot, lbs	79.8	83.8	86.9
Per cent. of drawn to live weight	79	78	79
Range of individual drawn weights, lbs	4.0–6.3	4.1–6.3	4.8–7.7
Average of individual drawn weights, lbs	5.0	5.6	5.8
Range of spleen weights, grams	2.1–9.2	2.3–13.0	1.9–7.8
Average of spleen weights, grams	4.3	4.6	4.2
Range of liver weights, grams	34.5–49	35.7–80.2	30.2–55.5
Average of liver weights, grams	41.9	45.0	43.3

The final weights of the lots were so nearly alike that a consideration of the individuals becomes necessary to determine whether the small differences were apparent or real. The caponizing was done when the cockerels were rather young, and a spoon hook was not used in the operation. Consequently there was a large proportion of "slips" among the birds, and notes on the development of the testes, color of head and size of comb were therefore taken. Lots I and II contained the same proportion of true capons, and the range in individual weights was about the same. There was only about five per cent. difference in the drawn weight of the birds whether cotton-seed meal or beef scrap furnished the same proportion of a given amount of nitrogen in feeds having the same nutritive ratio and fed at the same rate. Lot III contained a smaller proportion of true capons than the other two lots; and although in case of this lot their average weight was greater than that of the "slips," there was practically no such difference in case of the other lots. It seems fairly reasonable therefore to attribute the four per cent. increase in the drawn weight of lot III over that of lot II to the increase in the proportion of protein furnished by the larger amount of beef scrap.

It should be borne in mind that as the capons grew larger they did not require food with so large a proportion of protein, and that even though corn and corn meal were used in liberal proportion, with only as much bran as was necessary to prevent the mash from being sticky, nevertheless more than half of the required protein was supplied in the feeds other than the protein concentrates. Any specific effect of these concentrates therefore would have less opportunity to show itself than if larger proportions could have been used without fulfilling the optimum protein requirement.

The difference in the rate of growth of lots II and III was so small that one hesitates to assert positively that the larger gain in the case of lot III was due to the larger amount of protein, resulting from a replacement of a portion of the corn meal by the extra amount of beef scrap, and that protein had been proven thereby to be the limiting factor. At all events, *when fed in equal amounts* during a a number of months, the ration containing cotton-seed meal was nearly as good as the similar one containing beef scrap, and, so far as could be observed, exerted no deleterious effect.

EXPERIMENT II. COTTON-SEED MEAL VERSUS BEEF SCRAP, EACH IN RATIONS HAVING THREE DIFFERENT NUTRITIVE RATIOS.

This experiment was begun December 3, 1909, with Rhode Island Red chicks about six weeks old. Six equal lots of twenty chickens each were used in the experiment. At any given time the relation of the feeds for these lots differed in the proportion of corn meal and protein concentrate, which latter consisted of cotton-seed meal for lots I, III and V, and of beef scrap for lots II, IV and VI. During the first four weeks the approximate nutritive ratio was 1:3 for lots I and II, 1:4 for lots III and IV, and 1:5 for lots V and VI; and for the remaining time the nutritive ratios were all about one unit wider, i. e. 1:4, 1:5 and 1:6, respectively. In the case of each lot, fresh food in the form of cabbage constituted a definite proportion of the rations; it was not included in calculating the nutritive ratios.

The rations having the same nutritive ratio contained equal percentages of nitrogen, and also of nitrogen-free extract, plus ether extract multiplied by 2:3. Furthermore, practically the same percentage of nitrogen was furnished in the cotton-seed meal and in the beef scrap.

During the first four weeks of the experiment all lots received the same amount of food per chick, but because the rations containing cotton-seed meal were not eaten so freely as those containing beef scrap, all three of the lots receiving the latter were fed uniformly a larger amount than was fed to the cotton-seed meal lots. During consecutive fortnights they consumed 40, 25, 25, 10, 15, 15 and 20 per cent. more than the cotton-seed meal lots would consume, and consequently made larger gains. The live weights of the chicks were taken weekly and the amount of feed was evened up once in two weeks.

In weight parts per thousand of the entire feed, exclusive of the cabbage, the following was the basal ration common to all lots:

	From Dec. 3 to Dec. 30, 1909.	From Dec. 31, 1909 to April 8, 1910.
Cracked wheat	136	165
Cracked corn	363	435
Ground clover	69	47
Wheat bran	69	94
Bone ash	55	47
	692	788

In addition to this basal ration the following parts per thousand were received by the different lots:

	From Dec. 3 to Dec. 30, 1909.					
Lot.	I.	II.	III.	IV.	V.	VI.
Corn meal	0	89	103	162	185	220
Cotton-seed meal	308	0	205	0	123	0
Beef scrap	0	219	0	146	0	88
	308	308	308	308	308	308

	From Dec. 31, 1909 to April 8, 1910.					
Lot.	I.	II.	III.	IV.	V.	VI.
Corn meal	0	61	71	112	127	152
Cotton-seed meal	212	0	141	0	85	0
Beef scrap	0	151	0	100	0	60
	212	212	212	212	212	212

During the first four weeks of the experiment the amounts of scratch feed (the cracked corn and wheat) and mash were equal; subsequently, fifty per cent. more scratch feed than mash was fed.

The following analyses of the above-mentioned feeds are given in full since they represent in a general way the nature of the feeds used in the experiments as a whole, although of course different lots were fed involving other determinations especially of nitrogen.

Percentage composition of feeds used in Experiment II.

	Cracked wheat.	Cracked corn.	Ground clover.	Wheat bran.	Corn meal.	Cotton-seed meal.	Beef scrap.
Water	12.16	11.77	8.25	10.00	11.67	7.17	7.69
Ash	1.76	1.14	6.87	8.06	1.49	6.02	21.14
Fiber	2.23	0.99	24.41	9.84	1.97	10.72	0.00
Protein	12.25	8.44	13.31	15.00	8.63	42.44	56.50
Ether-extract (fat)	1.97	3.34	2.35	4.69	4.24	9.51	13.86
Non-nitrogenous extract matter	69.63	74.32	44.81	52.41	72.00	24.14	0.81
	100.00	100.00	100.00	100.00	100.00	100.00	100.00

In Tables II and III may be found the record of the feed consumed and of the growth of the chicks.

TABLE II. *Total feed, including cabbage in air-dry condition, consumed during the fortnight preceding the successive dates; and the live weight of chicks on the given dates, all given in pounds per ten chicks.*

	Weight of air-dry feed per fortnight.		Live weight of chicks.					
			On cotton-seed meal rations.			On beef scrap rations.		
1909.	Lots I, III or IV.	Lots II. IV or VI.	Lot I. (Narrowest ration.)	Lot III. (Medium ration.)	Lot V. (Widest ration.)	Lot II. (Narrowest ration.)	Lot IV. (Medium ration.)	Lot VI. (Widest ration.)
Dec. 3	.....	.....	4.06	3.95	4.28	4.13	4.11	4.12
Dec. 17	15.78	15.78	5.20	5.15	5.60	5.60	5.58	5.71
Dec. 31	20.64	20.64	6.72	7.00	7.50	7.67	7.36	7.19
1910.								
Jan. 14	25.64	35.90	8.83	9.00	9.66	12.06	11.53	11.31
Jan .28	30.86	38.57	11.75	12.15	12.88	16.18	15.61	14.95
Feb. 11	36.85	46.07	15.50	16.15	16.90	21.50	21.50	19.40
Feb. 25	39.12	43.11	17.78	18.38	19.28	23.71	23.38	21.97
Mar. 11	50.55	58.13	21.93	22.80	23.25	29.70	28.41	28.13
Mar. 25	52.04	59.84	23.86	25.65	26.01	31.86	33.07	31.40
Apr. 8	55.00	66.00	26.74	29.06	29.21	35.31	36.70	36.00
Total	326.48	384.04						

TABLE III. *Gain in live weight in pounds per ten chicks during the fortnight preceding the successive dates.*

	On cotton-seed meal rations.			On beef scrap rations.		
1909.	Lot I. (Narrowest ration.)	Lot III. (Medium ration.)	Lot V. (Widest ration.)	Lot II. (Narrowest ration.)	Lot IV. (Medium ration.)	Lot VI. (Widest ration.)
Dec. 17	1.14	1.20	1.42	1.47	1.47	1.59
Dec. 31	1.52	1.95	1.90	2.07	1.78	1.48
1910.						
Jan. 14	2.11	2.00	2.16	4.39	4.17	4.12
Jan. 28	2.92	3.15	3.22	4.12	4.08	3.64
Feb. 11	3.75	4.00	4.12	5.32	5.89	4.45
Feb. 25	2.28	2.23	3.28	2.21	1.88	2.57
Mar. 11	4.15	4.42	3.97	5.99	5.03	6.16
Mar. 25	2.93	2.85	2.76	2.16	4.56	3.27
Apr. 8	2.88	3.41	3.20	3.45	3.63	4.60
Total	24.68	25.21	26.03	31.18	32.49	31.88

During the first four weeks of the experiment all lots received the same amount of food, and the nutritive ratios of the different rations were narrower than they were later. It is of interest to notice in Table II that at the termination of this period, December 31, the live weights of the cotton-seed meal lots increased with the widening of the nutritive ratio, whereas with the beef scrap lots the reverse was true.

After the first month of the experiment the rations were changed so that the nutritive ratio in each case was wider than before. Furthermore, inasmuch as the beef scrap lots seemed ready to consume a larger amount of feed than the cotton-seed lots, it was also decided to allow the beef scrap lots to eat as much as was consumed by that one of them which ate its feed least readily. As a result of this they consumed more feed and made faster gains than did the cotton-seed lots; the greatest gains in case of the beef scrap lots, for the second month also, were made by the chicks receiving feed with the narrowest ratio; but, after that, the gains were just as likely to be greatest in the case of one of the other lots.

Lot I, which received the largest proportion of cotton-seed meal, usually consumed their feed less readily than the other cotton-seed meal lots, and weighed less at the end of the experiment. It may be observed likewise that toward the end of the experiment the similar ration with beef scrap resulted in slightly less live weight than the other lots. It happened that the ratio of cockerels to pullets proved to be less in these two lots (I and II) than in the others, the sexes being about equally divided; whereas in the other lots there were more than twice as many cockerels as pullets. Not knowing whether, with a given amount of food, cockerels or pullets make the faster growth, it is not possible to make a strict comparison of the lots having food of the narrowest nutritive ratio, with the others. If pullets make less growth than cockerels on a given amount of food, then the apparent slight inferiority of the two lots in question may be attributable to this cause.

The experiment shows on the whole that there was no advantage in the partial replacement of the corn meal in the rations having the widest nutritive ratio, with either protein concentrate; and also that there was practically a sufficient amount of protein in any of the rations to supply the needs of the chicks.

EXPERIMENT III. THE EFFECT OF FEEDING COTTON-SEED MEAL IN ADDITION TO A WELL-BALANCED RATION.

This experiment was begun with two lots of twenty White Plymouth Rock chicks each, when the latter were three weeks old.

The object was to ascertain whether cotton-seed meal given as an extra amount of feed to a well-balanced ration would be beneficial or toxic to chicks. Aside from the cotton-seed meal which was fed to lot II, both lots consumed the same amount of total feed composed of the following:

MASH.	Per cent.
Clover meal	14
Wheat bran	14
Corn meal	33
Beef scrap	29
Bone ash	5
Ground limestone	5
	100

SCRATCH FEED.	
Wheat	27
Cracked corn	73
	100

At first the same amount of scratch feed and basal mash was fed but since the chicks seemed to eat the mash the more readily, its proportion was increased until twice as much of it was given as of the scratch feed. Later, however, when the chicks would take more of the scratch feed the proportion fed at first was again adopted.

At first the cotton-seed meal given to lot II was about 7 per cent. of the rest of the feed. Not until the ninth week did it exceed 20 per cent., while at the close it constituted as much as 30 per cent. It may be seen by reference to the weekly live weights given in Table IV that the cotton-seed meal had practically no effect during the first half of the experiment; but as the proportion was increased, lot II, which was fed *ad libitum* generally gained more than lot I. The chicks in lot I, which received about a fifth less food toward the end of the experiment, were of course underfed at that time.

The mortality was rather high, but about equal in both lots. Post mortem examinations made by Dr. P. B. Hadley of the station failed to reveal any differences probably attributable to the cotton-seed meal. It is very likely only a peculiar coincidence that an examination of seven chicks which received no cotton-seed meal revealed only one which was with certainty free from coccidiosis. whereas seven of the eight examined from the cotton-seed meal lot were unaffected.

The experiment furnished no evidence of toxicity due to cotton-seed meal. If there was any ill effect, it was masked by the advantages of adding the extra feed to a deficient amount, and thereby increasing the growth of the chicks.

TABLE IV. *Record in pounds per ten chicks, of lot I (without cotton-seed meal) and lot II (with cotton-seed meal in additional to the feed of lot I).*

DATE.	Live weight.		During the week preceding the successive dates.			
			Gain in live weight.		Cotton-seed meal for only lot II.	Other feed for lots I and II alike.
1910.	Lot I.	Lot II.	Lot I.	Lot II.		
Sept. 16	2.01	2.04	......	......	......	......
Sept. 23	2.20	2.08	.36	.08	.12	1.67
Sept. 30	2.73	2.54	.49	.43	.17	2.06
Oct. 7	3.00	3.06	.25	.72	.22	2.20
Oct. 14	3.92	3.75	.83	.64	.36	2.77
Oct. 21	5.04	4.83	1.06	1.08	.50	3.48
Oct. 28	6.25	6.30	1.21	1.47	.53	4.37
Nov. 4	7.08	7.45	.83	1.15	.81	5.91
Nov. 11	8.58	8.93	1.49	1.48	.75	5.25
Nov. 18	10.01	10.63	1.45	1.70	1.33	5.83
Nov. 25	11.19	12.41	1.18	1.78	1.59	6.97
Dec. 2	12.25	14.40	1.06	1.99	1.73	6.04
Dec. 9	14.19	17.00	1.96	1.75	2.38	8.00
Dec. 16	15.96	18.69	1.78	1.69	1.79	5.99
Total			13.95	15.96	12.28	60.54

EXPERIMENT IV. THE EFFECT OF SUPPLEMENTING A UNIFORM BASAL RATION WITH PROTEIN-FREE FEED AND WITH PROTEIN IN BEEF SCRAP AND IN COTTON-SEED MEAL.

Barred Rock chicks about four weeks old were started in the experiment October 15, 1910. There were six lots of eighteen chicks each. All lots received the same amount of a basal ration which was very deficient in protein. Duplicate lots I and V were given no other feed than the basal ration; lot VI received in addition to the above, non-nitrogenous feed composed of starch, sugar and cotton-seed oil, in order to show whether the chicks could possibly make use of such ingredients in addition to the liberal proportions contained in the basal ration. Lots II and III received the same moderate amount of nitrogen in addition to the basal ration, lot II in cottonseed meal, and lot III in beef scrap. Lot IV received a larger addition of protein in beef scrap, the attempt being made to regulate the amount so that this lot would make the most rapid gains and show thereby that lots II and III were receiving a sub-optimum amount of protein, or less than was required for the greatest rate of increase in live weight.

The following was the basal ration in weight parts:

Basal Mash.	
Rolled oats	10
Corn meal	195
Cotton-seed meal	5
Linseed meal	5
Beef scrap	5
Bone meal	20
Wheat bran	20
Ground clover	20
Calcium carbonate or ground limestone	10
Quartz sand	10
Total	300

Basal Scratch Feed.	
Cracked corn	90
Cracked rice	40
Wheat	*20
	150

At the beginning of the experiment one-half as much scratch feed as basal mash was given; but this proportion was gradually increased until, in the sixth and successive nine weeks, equal amounts of scratch feed and basal mash were fed per an equal number of chicks in each lot.

Lot II received during the three successive five-week periods an addition of cotton-seed meal equal to 21, 40 and 50 per cent. respectively of the basal mash; and lot III received, similarly, additions of beef scrap equal to 13.5, 31 and 39 per cent. of the basal mash. Equal amounts of nitrogen were given in the two concentrates, even though the proportion of the concentrates to the mash varied. Lot IV received during the first five weeks an addition of beef scrap equal to 25 per cent. of the basal mash, and during the remainder of the experiment an addition of 50 per cent. Lot VI received during the first five weeks an addition of a mixture of nine parts of starch and one part of cotton-seed oil, equal to 13.5 per cent. of basal mash; and during the remainder of the experiment it received an addition of 31 per cent. of a mixture composed of five parts of starch, four parts of sugar and one part of cotton-seed oil.

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*Replaced by rice during the last five weeks.

In addition to the uniform amount of the basal ration, previously mentioned, all lots likewise received, as a succulent feed, a constant proportion of mangel wurzels.

Usually one of the lots receiving only the basal ration, or the one receiving protein-free feed in addition, ate its feed less readily than the others and thus determined the amount of basal ration which was given to the different lots.

At the conclusion of the experiment each lot consisted of the following:

Lot.	I.	II.	III.	IV.	V.	IV.
Cockerels	10	8	7	9	6	5
Pullets	4	5	5	7	8	7
Total	14	13	12	16	14	12
Per cent. of Cockerels	71	62	58	56	46	42

The live weight, gain in weight, and amount of feed consumed for each week may be found in Tables V, VI and VII.

TABLE V. *Live Weight in pounds per ten chicks.*

Lot.	I.	II.	III.	IV.	V.	VI.
Kind of feed in excess of the basal ration.	None.	Cotton-seed meal.	Beef scrap.	Larger Amount of beef scrap.	None.	Protein-free feed.
1910.						
Oct. 15................	2.06	2.05	2.03	2.07	2.04	2.07
Oct. 22................	2.42	2.42	2.43	2.59	2.24	2.31
Oct. 29................	2.74	3.04	2.95	3.24	2.58	2.73
Nov. 5................	3.18	3.54	3.51	3.89	2.66	3.11
Nov. 12................	3.48	4.00	4.06	4.58	3.22	3.23
Nov. 19................	3.95	4.96	4.86	5.53	3.75	3.79
Nov. 26................	4.41	5.58	5.64	6.56	4.02	4.11
Dec. 3................	4.91	6.65	6.80	7.45	4.47	4.65
Dec. 10................	5.36	7.73	8.00	8.76	5.23	5.48
Dec. 17................	5.98	8.46	8.54	9.65	5.50	6.01
Dec. 24................	6.89	9.59	9.61	11.05	6.18	6.53
Dec. 31................	7.14	10.64	10.57	12.19	6.81	7.00
1911.						
Jan. 7................	7.51	11.71	12.08	13.83	7.40	7.51
Jan. 14................	7.73	12.51	13.15	15.09	7.76	7.71
Jan. 21................	8.63	13.69	14.77	16.54	8.56	8.86
Jan. 28................	9.36	14.90	16.31	18.83	9.24	9.15

TABLE VI. *Gain in live weight (pounds) per ten chicks during the week preceding the successive dates.*

Lot.	I.	II.	III.	IV.	V.	VI.
Kind of feed in excess of the basal ration.	None.	Cotton-seed meal.	Beef scrap.	Larger amount of beef scrap.	None.	Protein-free feed.
1910.						
Oct. 22................	.36	.36	.32	.53	.19	.24
Oct. 29................	.32	.53	.48	.57	.34	.42
Nov. 5................	.45	.52	.58	.66	.10	.40
Nov. 12................	.30	.46	.61	.69	.21	.12
Nov. 19................	.47	.80	.80	.95	.53	.44
Nov. 26................	.20	.61	.77	1.03	.27	.31
Dec. 3................	.50	.66	.64	.89	.45	.55
Dec. 10................	.39	1.08	.84	1.31	.76	.61
Dec. 17................	.43	.73	.54	.89	.27	.53
Dec. 24................	.76	1.13	1.07	1.39	.69	.53
Dec. 31................	.25	1.05	1.20	1.14	.63	.27
1911.						
Jan. 7................	.41	1.08	1.52	1.64	.54	.51
Jan. 14................	.21	.79	1.07	1.26	.36	.20
Jan. 21................	.90	1.17	1.62	1.45	.77	.43
Jan. 28................	.73	1.21	1.54	2.29	.69	.29
Total................	6.68	12.18	13.60	16.69	6.80	5.85

TABLE VII. *Air-dry feed (including also the mangel wurzels calculated to that condition) consumed per ten chicks during the week preceding the successive dates.*

Lot.	I and V each.	II.	III.	IV.	VI.
Kind of feed in excess of basal ration.	None.	Cotton-seed meal.	Beef scrap.	Larger amount of beef scrap.	Protein-free feed.
1910.					
Oct. 22	1.66	1.88	1.81	1.95	1.81
Oct. 29	2.25	2.50	2.40	2.57	2.42
Nov. 5	2.43	2.61	2.52	2.68	2.61
Nov. 12	2.76	3.07	2.97	3.14	2.97
Nov. 19	2.61	2.89	2.81	3.01	2.80
Nov. 26	2.98	3.55	3.42	3.66	3.42
Dec. 3	3.24	3.88	3.75	4.05	3.74
Dec. 10	3.79	4.54	4.36	4.73	4.37
Dec. 17	3.67	4.38	4.22	4.58	4.31
Dec. 24	4.33	5.57	5.36	5.41	5.04
Dec. 31	4.55	5.45	5.40	5.66	5.26
1911.					
Jan. 7	4.60	5.74	5.49	5.75	5.31
Jan. 14	4.63	5.78	5.82	5.81	5.34
Jan. 21	5.11	6.38	6.11	6.37	5.89
Jan. 28	4.43	5.52	5.27	5.51	5.09
Total	53.04	63.74	61.71	64.88	60.39

Lots I and V which received only the basal ration of course made small gains. Lot VI, although it was given 14 per cent. more feed than lots I and V, in the form of starch, granulated sugar and cotton-seed oil, failed to make any greater growth, because there was no protein in the additional feed; lot III, on the other hand, which was fed a similar amount of feed in addition to the basal ration, made about 70 per cent. more growth, due to the fact that the added beef scrap contained about 62 per cent. of protein; and lot II, which was given the same amount of additional nitrogen, but in cotton-seed meal, weighed about 60 per cent. more at the end of the experiment than those chicks which received only the protein contained in the basal ration. Lot IV was given more protein in beef scrap than any other lot and weighed about twice as much as those which received only the basal ration.

It is believed that the experiment was so conducted that the additional growth of lots II and III was nearly all attributable to the given amount of protein in the cotton-seed meal and beef scrap, respectively, although it is possible that the other ingredients of the concentrates may have been of some use to these lots on account of the fact that the chicks grew faster and became larger than those receiving only the basal ration. Although the non-nitrogenous ingredients added to the basal ration scarcely affected the growth of the chicks, this cannot be taken as positive proof that in case of the larger chicks, the similar ingredients of the added concentrates were without effect.

At the conclusion of the feeding experiment the chicks were bled and, after the removal of all the feathers, were weighed (dressed weight). They were then prepared as usual for cooking, the head and legs being discarded and the giblets retained, and were weighed again (weight prepared for cooking). They were cooked by placing each lot in a covered vessel, to which a small amount of water was added, and subjecting the whole to a thorough cooking in a steam box. Care was taken to subject the different lots to the same treatment, especially lots II and III, which were cooked at the same time. The meat was kept warm while it was removed from the bones as thoroughly as possible by hand. The amount of soup and fat sticking to the bones was, of course, somewhat indefinite, but it is believed that more of the edible portions were removed than would usually be the case during human consumption. The soup was concentrated and mixed with the minced meat, which likewise included not only the gizzards, hearts and livers, but also the skin; the mixture will be referred to as the edible part, or meat and soup.

Water, nitrogen, and ether-extract or fat were determined in the bones, as well as in the edible part. The data concerning the dressed chicks may be found in Table VIII.

TABLE VIII. *Nitrogen, fat and ash in steamed chickens.*

(The weights are given in grams per chick.)

Lot.	I.	II.	III.	IV.	V.	VI.
Kind of feed in excess of the basal ration.	None.	Cotton-seed meal.	Beef scrap.	Larger amount of beef scrap.	None.	Protein-free feed.
Weight, bled and picked	409	689	693	773	409	422
Weight, prepared for cooking	262	438	489	543	253	261
Per cent. of dry matter in chicks prepared for cooking	34.58	32.48	33.74	33.59	35.34	37.03
Weight, dry cooked meat and soup	69.2	107.1	124.4	137.6	67.7	76.2
Weight, dry cooked bones	21.3	35.1	40.6	44.7	21.9	20.4
Weight, dry cooked total	90.5	142.1	165.0	182.3	89.6	96.6
Per cent. of bones in dry cooked part	24	25	25	25	24	21
Weight of Nitrogen in cooked meat and soup	6.74	11.62	15.23	15.18	7.09	6.74
Weight of Nitrogen in cooked bones	1.09	2.11	1.98	2.46	1.18	1.05
Weight of Nitrogen in cooked total	7.83	13.73	17.20	17.64	8.26	7.79
Weight of Fat in cooked meat and soup	24.43	28.80	35.48	40.51	21.57	31.87
Weight of Fat in cooked bones	4.76	6.67	7.51	7.76	4.91	5.22
Weight of Fat in cooked total	29.19	35.48	42.99	48.27	26.47	37.09
Weight of Crude Ash in cooked meat and soup	2.47	3.96	4.53	4.52	2.64	2.42
Weight of Crude Ash in cooked bones	8.24	13.33	16.14	18.67	8.35	7.49
Weight of Crude Ash in cooked total	10.71	17.29	20.67	23.19	10.98	9.91
Per cent. of Nitrogen in dry cooked meat and soup	9.74	10.86	12.25	11.04	10.47	8.84
Per cent. of Nitrogen in dry cooked bones	5.07	6.01	4.86	5.50	5.37	5.12
Per cent. of Nitrogen in dry cooked total	8.65	9.66	10.43	9.68	9.23	8.06
Per cent. of Fat in dry cooked meat and soup	35.30	26.90	28.53	29.45	31.88	41.80
Per cent. of Fat in dry cooked bones	22.19	19.04	18.48	17.36	22.41	25.57
Per cent. of Fat in dry cooked total	32.27	24.96	26.05	26.49	29.57	38.37
Per cent. of Crude Ash in dry cooked meat and soup	3.57	3.70	3.64	3.29	3.90	3.17
Per cent. of Crude Ash in dry cooked bones	38.44	38.03	39.70	41.78	38.13	36.71
Per cent. of Crude Ash in dry cooked total	11.85	12.17	12.53	12.73	12.27	10.25

It may be seen that although the dressed weight of the cotton-seed lot was about the same as that of the beef-scrap lot receiving the same amount of nitrogen, the shrinkage in preparing for cooking was more in case of the former; and, furthermore, the percentage of nitrogen in the cooked material was less. Consequently, in this experiment, considerably less of the nitrogen was recovered in case of the cotton-seed meal than in case of the beef scrap, although this was not true in subsequent experiments. Further discussion concerning the chemical data will be taken up on later pages.

EXPERIMENT V. A COMPARISON OF THE EFFECT OF ADDING TO A UNIFORM BASAL RATION, NITROGEN-FREE FEED, AN EQUAL AMOUNT OF NITROGEN IN COTTON-SEED MEAL AND IN BEEF SCRAP, AND A LARGER AMOUNT OF THE LATTER.

This experiment was begun March 13, 1911, with four lots, each composed of twenty White Wyandotte chicks three weeks old.

All received the same amount of mangel wurzels and of the following basal ration in parts by weight:

Basal Mash.

Corn meal	195	Limestone	10
Ground alfalfa	20	Quartz sand	10
Wheat bran	20	Cotton-seed meal	5
Bone meal	10	Linseed meal	5
		Beef scrap	5

Total,—300.

Basal Scratch Feed.

Cracked corn	180
Cracked rice	120
	300

In addition to the uniform feed, lot I received a mixture of nitrogen free feeds composed of 5 weight parts of corn starch, 4 of sugar, and 1 of mutton fat, in amount equal to 34 per cent. of the basal mash; lot II received beef scrap equal to 30 per cent. of the basal mash; lot III received cotton-seed meal equal to 38 per cent. of the basal mash and furnishing the same amount of nitrogen as the additional amount of beef scrap fed to lot II; lot IV received an extra amount of beef scrap, equal to 38 per cent. of the basal mash.

It was expected that the basal ration would furnish as large an amount of non-nitrogenous ingredients as the chicks could make use of, as was the case in the last experiment, in which practically the same basal ration was adopted; nevertheless, an additional amount was given to lot I, with the intention of providing at least as much of the non-nitrogenous constituents as was supplied in the beef scrap and cotton-seed meal which were added to lots II and III, respectively.

The extra amount of beef scrap was added to lot IV to show that maximum growth was not attained by lots II and III, and that opportunity was thus afforded for the medium amount of nitrogen supplied to lots II and III, to exert its full effect.

At the conclusion of the experiment the number of chicks remaining, and their range in dressed weight were as follows:

Lot I, fifteen chicks, between .63 and 1.06 pounds.
Lot II, twelve chicks, between .69 and 1.83 pounds.
Lot III, ten chicks, between 1.36 and 1.92 pounds.
Lot. IV, eleven chicks, between .87 and 2.25 pounds.

There were more pullets than cockerels, but fortunately the proportion was about the same in all lots. The records concerning live weight, gain in weight and feed consumed are included in Tables IX, X and XI.

Lots I, II and III were steamed and analyzed in a manner similar to that described in the preceding experiment. The results so secured may be found in Table XII.

TABLE IX.—*Live weight in pounds per ten chicks.*

Lot.	I.	II.	III.	IV.
Kind of feed in excess of basal ration.	Protein-free feed.	Beef scrap.	Cotton-seed meal.	Larger amount of beef scrap.
1911.				
Mar. 13	1.66	1.36	1.77	1.44
Mar. 20	1.96	1.96	2.22	2.10
Mar. 27	2.36	2.73	2.79	2.75
April 3	2.63	3.16	3.15	3.22
April 10	3.08	3.67	3.62	3.74
April 17	3.33	4.34	4.17	4.29
April 24	3.49	4.35	4.23	5.14
May 1	3.94	5.58	5.23	6.45
May 8	4.40	5.93	5.79	7.25
May 15	4.80	6.86	6.75	8.32
May 22	5.58	8.32	8.29	9.86
May 29	6.00	9.46	10.12	10.86
June 5	7.02	11.28	11.94	13.54
June 12	7.80	12.27	13.97	15.00
June 19	8.63	13.26	15.80	16.41
June 26	9.21	15.10	17.70	19.13

TABLE X.—*Gain in live weight in pounds per ten chicks during the week preceding the successive dates.*

Lot.	I.	II.	III.	IV.
Kind of feed in excess of basal ration.	Protein-free feed.	Beef scrap.	Cotton-seed meal.	Larger amount of beef scrap.
1911.				
Mar. 20	.31	.61	.46	.66
Mar. 27	.40	.72	.57	.65
April 3	.27	.42	.36	.47
April 10	.46	.52	.44	.45
April 17	.49	1.20	1.05	.79
April 24	.23	.15	(—.15)	.63
May 1	.58	1.27	1.00	1.17
May 8	.29	.76	.62	.88
May 15	.40	.93	.96	1.06
May 22	.78	1.46	1.54	1.55
May 29	.42	1.14	1.39	1.00
June 5	1.02	1.82	1.82	2.68
June 12	.78	.99	2.03	1.45
June 19	.83	.99	1.83	1.41
June 26	.57	1.84	1.90	2.72
Total	7.83	14.82	15.82	17.57

TABLE XI.—*Air-Dry feed (including also the mangel wurzels calculated to that condition) consumed in pounds per ten chicks during the week preceding the successive dates.*

Lot.	I.	II.	III.	IV.
Kind of feed in excess of basal ration.	Protein-free feed.	Beef scrap.	Cotton-seed meal.	Larger amount of beef scrap.
1911.				
Mar. 20	1.67	1.65	1.70	1.70
Mar. 27	2.75	2.70	2.80	2.80
April 3	2.36	2.32	2.40	2.40
April 10	2.62	2.58	2.68	2.68
April 17	3.56	3.52	3.64	3.64
April 24	2.23	2.19	2.33	2.33
May 1	2.78	2.72	2.94	2.94
May 8	4.29	4.18	4.33	4.33
May 15	4.73	4.64	4.59	4.59
May 22	4.73	4.64	4.59	4.59
May 29	4.73	4.64	4.62	4.62
June 5	7.07	6.94	7.22	7.22
June 12	5.51	5.41	5.60	5.60
June 19	6.29	6.17	6.34	6.34
June 26	7.07	6.94	7.22	7.22
Total	62.39	61.24	63.00	63.00

TABLE XII. *Nitrogen, fat and ash in steamed chicks.*

(The weights are given in grams per chick.)

Lot. Kind of feed in excess of basal ration.	I. Protein-free feed.	II. Beef scrap.	III. Cotton-seed meal.	IV. Larger amount of beef scrap.
Weight, bled and picked	379	604	713	737
Weight, prepared for cooking	272	484	528	554
Per cent. of dry matter in chicks prepared for cooking	33.34	34.78	34.11	......
Weight of dry cooked meat and soup	64.5	126.3	139.5	......
Weight of dry cooked bones	26.6	41.9	40.3	......
Weight of dry cooked total	91.1	168.2	179.8	......
Per cent. of bones in cooked part, dry	29	25	22	......
Weight of Nitrogen in cooked meat and soup.	5.87	11.26	13.28	......
Weight of Nitrogen in cooked bones	1.53	2.43	2.29	......
Weight of Nitrogen in cooked total	7.41	13.68	15.57	......
Weight of Fat in cooked meat and soup	24.08	51.82	55.17	......
Weight of Fat in cooked bones	7.87	10.06	9.64	......
Weight of Fat in cooked total	31.95	61.89	64.81	......
Weight of Crude Ash in cooked meat and soup	2.05	4.21	4.76	......
Weight of Crude Ash in cooked bones	8.45	14.52	15.27	......
Weight of Crude Ash in cooked total	10.49	18.72	20.04	......
Per cent. of Nitrogen in dry cooked meat and soup	9.10	8.91	9.52	......
Per cent. of Nitrogen in dry cooked bones	5.77	5.79	5.68	......
Per cent. of Nitrogen in dry cooked total	8.13	8.13	8.66	......
Per cent. of Fat in dry cooked meat and soup.	37.33	41.03	39.54	......
Per cent. of Fat in dry cooked bones	29.58	24.02	23.90	......
Per cent. of Fat in dry cooked total	35.07	36.79	36.03	......
Per cent. of Crude Ash in dry cooked meat and soup	2.05	4.21	4.76	......
Per cent. of Crude Ash in dry cooked bones	31.74	34.65	37.88	......
Per cent. of Crude Ash in dry cooked total	11.52	11.13	11.14	......

The average chick of lot I, which received no nitrogen in addition to the 42.3 grams in the basal ration, contained in the cooked portion 7.4 grams of nitrogen. As the result of the addition of 35.4 grams of nitrogen to the feed the amount in the average cooked chick was increased 6.3 grams when the beef scrap was added, and 8.2 grams when cotton-seed meal was the addition. By reference to the preceding tables it may be seen that the chickens in the cotton-seed meal lot were heavier than those in the corresponding beef scrap lot (II) at the beginning of the experiment and that their superior gains were confined to the last few weeks.

EXPERIMENT VI. THE EFFECT OF REVERSING COTTON-SEED MEAL AND BEEF SCRAP WHEN ADDED TO A UNIFORM BASAL RATION.

The White Wyandotte chicks in this experiment were hatched from eggs purchased later from the same source as those used in the preceding experiment, and the chicks were the same age when the experiment was begun. The basal feeds in the two experiments were likewise the same. Twenty-one chicks were selected for each lot, V and VI. During the first fifteen weeks, lot V received cotton-seed meal in addition to the basal ration, as did lot III of the preceding experiment; and lot VI received an equal amount of nitrogen in beef scrap, the same as lot II of the preceding experiment; during the sixteenth week, the protein concentrates were gradually reversed, and throughout the remainder of the experiment lot V received the beef scrap, and lot VI the cotton-seed meal. About a third of each lot proved to be cockerels. The remaining data concerning the experiment are given in Table XIII.

TABLE XIII.—*The record in pounds per ten chicks fed with equal amounts of a basal ration to which an equal amount of nitrogen in cotton-seed meal and beef scrap was added.*

	Live weight.		Gain in live weight during the week preceding the successive dates.		Air-dried feed* consumed during the week preceding the successive dates.	
1911.	Lot V. (C.S.Meal)	Lot VI. (Beef Scrap)	Lot V. (C.S.Meal)	Lot VI. (Beef Scrap)	Lot V. (C.S.Meal)	Lot VI. (Beef Scrap)
April 12..........	1.92	1.95	....	....	....	....
April 19..........	2.25	2.53	.36	.58	1.80	1.74
April 26..........	2.67	2.95	.41	.42	2.17	2.09
May 3..........	3.05	3.43	.38	.48	1.80	1.74
May 10..........	3.43	3.77	.38	.34	2.17	2.09
May 17..........	4.17	4.58	.74	.80	2.89	2.79
May 24..........	4.87	5.18	.70	.60	3.46	3.34
May 31..........	5.57	6.50	.70	1.18	4.02	3.87
June 7..........	6.55	7.47	.98	.87	5.16	5.01
June 14..........	7.06	8.46	.50	.98	4.59	4.44
June 21..........	8.19	9.42	1.14	.96	5.16	4.99
June 28..........	8.87	10 38	.68	.98	5.16	4.99
July 5..........	10.32	12.09	1.45	1.71	6.29	6.07
July 12..........	13.10	15.12	1.94	2.65	7.05	6.82
July 19..........	14.25	15.54	1.16	.42	7.05	6.82
July 26..........	15.60	16.91	1.34	1.37	7.05	6.82
Aug. 2..........	16.76	17.85	1.16	.94	6.37	6.46
	(Beef Scrap)	(C.S.Meal)	(Beef Scrap)	(C.S.Meal)	(Beef Scrap)	(C.S.Meal)
Aug. 9..........	19.37	19.84	2.24	1.99	8.38	8.67
Aug. 16..........	21.81	22.59	2.44	2.75	10.46	10.77
Aug. 23..........	24.82	25.33	3.01	2.75	10.46	10.78
Aug. 30..........	27.88	28.12	3.06	2.78	8.39	8.68
Sept. 6..........	28.31	28.97	.44	1.44	6.52	6.72
Sept. 13..........	31.15	31.30	2.84	2.34	10.46	10.78
Sept. 20..........	33.12	33.82	1.97	2.52	10.46	10.78
Sept. 27..........	35.19	35.29	2.06	1.47	10.46	10.78
Oct. 4..........	36.41	36.78	1.22	1.48	10.46	10.78
Oct. 11..........	37.50	37.38	1.09	.61	10.46	10.78

During the first fifteen weeks this experiment is strictly comparable with the preceding one, excepting that it was begun about a month later. The differences between the live weights attained during this period by the lots receiving either beef scrap or cotton-seed meal, on an equal nitrogen basis, were about neutralized in the two experiments, for the live weights in pounds per ten chicks of the cotton-seed meal lots were 17.70 in the former experiment and 15.60 in the latter; and, similarly, the live weights of beef scrap lots were 16.91 in the latter experiment and 15.10 in the former.

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*Including also mangel wurzels calculated to the air-dry condition.

It may be seen by reference to Table XIII that at the end of the first period in which lot V had received an addition of cotton-seed meal, it weighed less than lot VI, but that when the concentrates had been reversed during the latter part of the experiment, the two lots finally weighed about the same.

EXPERIMENT VII. THE EFFECT OF AN ADDITION TO A UNIFORM BASAL RATION, OF BAKED COTTON-SEED MEAL, AND OF UNBAKED COTTON-SEED MEAL WITH AND WITHOUT CALCIUM CARBONATE, IN COMPARISON WITH AN ADDITION OF BEEF SCRAP ON AN EQUAL NITROGEN BASIS.

The experiment was begun with four lots of thirty-five White Plymouth Rock chicks, about three weeks old. The basal ration was the same as in the last two experiments, except that calcium carbonate was added only to the rations for lots II, III and IV, and to those only until September 22. Granite grit was used.

Lots I and II of the experiment afforded a direct measure of the effect of calcium carbonate in connection with cotton-seed meal as the protein concentrate. Both lots received cotton-seed meal equal to 50.5 per cent. of the basal mash, whereas only lot II received calcium carbonate equal to 15 per cent. of the basal mash.

In order to determine which ration would be most readily eaten, this experiment differed from most of the others in that the various lots were given all the food they would consume. Early in the experiment it became evident that there was no advantage resulting from the addition of the finely ground limestone which was first used as a source of calcium carbonate; therefore, between September 2 and 22, the latter was added in powdered calcium carbonate, such as had been found beneficial with cotton-seed meal on other occasions. Since no advantage resulted from the calcium carbonate, however, it was given to none of the lots during the last five weeks of the experiment.

Lots II and III afforded a direct comparison between unbaked and baked cotton-seed meal, respectively, added on an equal nitrogen basis. For lot III the cotton-seed meal, mixed with water, was baked brown in an ordinary baking oven, and subsequently ground into a meal which was added to the mash. The chicks generally consumed even less of the feed containing the baked, than of that containing the unbaked cotton-seed meal and made smaller gains.

Lot IV, instead of receiving cotton-seed meal as additional food, was given sufficient beef-scrap to furnish the same proportion of nitrogen. The chicks consumed more feed than the other lots, as is usually the case when a ration containing beef scrap is fed *ad libitum*, and attained a greater final weight. At the end of the experiment the percentage of cockerels in each lot was as follows: Lot I, 32; lot II, 31; lot III, 38; and lot IV, 50.

Further detailed records are included in Tables XIV, XV and XVI.

TABLE XIV.—*Live weight per ten chicks.*

Lot.	I.	II.	III.	IV.
Kind of feed in excess of the basal ration.	Cotton-seed meal, but *no* Calcium Carbonate.	Cotton-seed meal.	Baked cotton-seed meal cake.	Beef scrap.
1911.				
July 14	2.20	2.27	2.29	2.22
July 28	2.47	2.53	2.47	2.39
Aug. 4	2.87	2.91	2.78	2.84
Aug. 11	3.64	3.40	3.29	3.20
Aug. 18	4.23	3.43	3.65	3.29
Aug. 25	5.03	4.13	3.83	4.10
Sept. 1	5.24	4.98	4.44	4.54
Sept. 8	6.58	5.75	5.16	5.37
Sept. 15	7.60	6.85	6.00	6.42
Sept 22	8.97	7.73	7.11	7.71
Sept. 29	10.34	9.23	8.36	9.37
Oct. 6	12.00	11.31	10.07	10.83
Oct. 13	13.36	12.42	11.54	13.15
Oct. 20	15.55	15.34	13.68	16.58
Oct. 27	17.00	17.11	16.88	18.96

TABLE XV.—*Gain in live weight per ten chicks during the week preceding the successive dates.*

Lot.	I.	II.	III.	IV.
Kind of feed in excess of the basal ration.	Cotton-seed meal, but *no* Calcium Carbonate.	Cotton-seed meal.	Baked cotton-seed meal cake.	Beef scrap.
1911.				
July 28 (for 2 weeks)	.21	.19	.12	.11
Aug. 4	.36	.24	.26	.29
Aug. 11	.66	.34	.29	.26
Aug. 18	.45	(—.16)	.17	.01
Aug. 25	.30	.32	.18	.52
Sept. 1	.63	.57	.41	.19
Sept. 8	.82	.78	.62	.68
Sept. 15	1.03	1.09	.84	1.04
Sept. 22	1.37	.88	1.10	1.38
Sept. 29	1.37	1.50	1.25	1.58
Oct. 6	1.66	2.08	1.71	1.46
Oct. 13	1.36	1.12	1.46	2.32
Oct. 20	2.19	2.92	2.14	3.48
Oct. 27	1.45	1.77	2.59	2.33
Total	13.86	13.64	13.14	15.65

TABLE XVI.—*Air-dry basal ration consumed in pounds per ten chicks during the week preceding the successive dates.*

Lot.	I.	II.	III.	IV.
Kind of feed in excess of the basal ration.	Cotton-seed meal, but *no* Calcium Carbonate.	Cotton-seed meal.	Baked cotton-seed meal cake.	Beef scrap.
1911.				
July 28 (for 2 weeks)	2.13	2.13	2.13	2.13
Aug. 4	1.37	1.43	1.44	1.47
Aug. 11	1.62	1.74	1.89	1.87
Aug. 18	1.15	1.14	1.23	1.12
Aug. 25	1.89	1.37	1.47	1.55
Sept. 1	2.04	1.94	1.63	1.81
Sept. 8	2.43	2.71	2.41	2.77
Sept. 15	3.47	3.38	3.14	3.66
Sept. 22	4.17	4.06	3.77	4.40
Sept. 29	4.17	4.06	3.77	4.40
Oct. 6	4.63	5.07	4.71	5.50
Oct. 13	4.63	5.07	4.71	6.23
Oct. 20	5.33	5.41	5.03	6.97
Oct. 27	5.33	5.41	6.43	6.96
Total	44.36	44.92	43.76	50.84

EXPERIMENT VIII. THE EFFECT OF SUPPLEMENTING A UNIFORM BASAL RATION WITH BEEF SCRAP AND WITH COTTON-SEED MEAL, WITH AND WITHOUT FURTHER ADDITIONAL PROTEIN-FREE FEED.

For this experiment Rhode Island Red chicks about four weeks old were equally divided into six lots of thirty-five chicks each. Each lot was fed the following basal ration at the same rate:

Basal Mash.	
Corn meal	198
Cotton-seed meal	10
Beef scrap	10
Bone meal	40
Ground alfalfa	40
Wheat bran	70
Limestone	20
	388

Basal Scratch Feed.	
Cracked corn	233
Cracked rice	155
	388

During the first seven weeks, twice as much scratch feed as basal mash was used; but during the last seven weeks equal amounts of each were fed.

Lots I to IV were given, in addition to the basal ration, a mixture of protein-free feed composed of 5 parts of corn starch, 4 parts of pulverized sugar and 1 part of mutton fat, in an amount equal to 50 per cent. of the basal mash; lots V and VI were not given this special mixture.

Furthermore, lot I received an addition of beef scrap equal to 60 per cent. of the basal mash, lots II and V an addition of beef scrap equal to 36 per cent., and lots III and VI an addition of cotton-seed meal equal to 50 per cent. Lots II, III, V and VI received the same amount of nitrogen and this was shown to be sub-optimum, or below the full requirements of the chicks for most rapid growth, by the fact that the extra protein added in the larger addition of beef scrap given to lot I produced a more rapid average growth of chicks.

Lot IV received no protein in addition to the basal ration, but the extra protein-free feed was the same in amount as the extra cotton-seed meal added to lot VI; therefore, lots IV and VI consumed the same amount of food per chick. Lot IV, however, attained a live weight per ten chicks of only 10.39 pounds, whereas lot VI weighed 16.54 pounds per ten chicks.

Inasmuch as the amounts of the supplementary feeds have been expressed in percentages only of the basal mash, it is evident that because of the larger proportion of the basal mash to scratch feed used during the latter half of the experiment, the proportions of the supplementary feeds to the combined basal mash and scratch feed were, for that period, 50 per cent. greater than during the first half of the experiment; e. g., an addition equalling 50 per cent. of the basal *mash* constituted 16⅔ per cent. of the entire basal *ration* during the first half of the experiment, and 25 per cent. during the last half.

Throughout nearly the entire experiment, lot IV, which received an addition of only protein-free feed to the basal mash, consumed its food least readily and thus determined the amount of basal ration which all received alike. They usually ate the mash more readily than the scratch feed, showing that the starch, sugar and mutton fat did not render the former distasteful.

At the close of the experiment there were the following percentages of cockerels in the different lots: Lot I, 55; lot II, 50; lot III, 54; lot IV, 38; lot V, 20; lot VI, 35. The data regarding live weight, gain in weight and feed consumed may be found in Tables XVII, XVIII and XIX.

TABLE XVII.—*Live weight per ten chicks.*

Lot.	I.	II.	III.	IV.	V.	VI.
Kind of feed in excess of basal ration.	Larger amount beef scrap and protein-free feed.	Beef scrap and protein-free feed.	Cotton seed meal and protein-free feed.	Protein-free feed.	Beef scrap.	Cotton-seed meal.
1911.						
Nov. 15..........	2.47	2.49	2.50	2.47	2.46	2.47
Nov. 22..........	3.05	2.96	2.94	2.77	2.89	2.87
Nov. 29..........	3.60	3.44	3.49	3.04	3.49	3.35
Dec. 6..........	4.22	3.89	3.91	3.31	3.98	3.85
Dec. 13..........	4.77	4.36	4.37	3.59	4.38	4.29
Dec. 20..........	5.53	5.09	4.97	4.12	4.87	4.89
Dec. 27..........	6.55	5.89	5.81	4.59	5.67	5.58
1912.						
Jan. 3..........	7.52	6.77	6.50	4.99	6.26	6.53
Jan. 10..........	9.14	8.22	7.66	5.57	7.33	7.91
Jan. 17..........	10.52	9.18	8.86	6.36	8.41	8.97
Jan. 24..........	12.39	10.74	11.02	7.23	9.99	10.66
Jan. 31..........	13.90	12.00	12.29	7.81	11.36	12.01
Feb. 7..........	15.17	13.42	13.31	8.22	12.88	13.05
Feb. 14..........	17.26	15.12	15.93	9.50	14.86	14.86
Feb. 21..........	19.45	16.73	17.82	10.39	16.18	16.54

TABLE XVIII.—*Gain in live weight per ten chicks during the week preceding the successive dates.*

Lot.	I.	II.	III.	IV.	V.	VI.
Kind of feed in excess of basal ration.	Larger amount beef scrap and protein-free feed.	Beef scrap and protein-free feed.	Cotton-seed meal and protein-free feed.	Protein-free feed.	Beef scrap.	Cotton-seed meal.
1911.						
Nov. 22..........	.59	.47	.44	.30	.45	.40
Nov. 29..........	.53	.49	.55	.27	.60	.49
Dec. 6..........	.62	.43	.42	.26	.49	.46
Dec. 13..........	.49	.44	.46	.25	.40	.45
Dec. 20..........	.76	.68	.59	.49	.49	.60
Dec. 27..........	1.03	.80	.79	.46	.81	.69
1912.						
Jan. 3..........	.89	.62	.69	.39	.59	.83
Jan. 10..........	1.34	1.36	1.14	.52	1.05	1.28
Jan. 17..........	1.10	.95	1.20	.64	.99	1.05
Jan. 24..........	1.67	1.57	1.78	.87	1.41	1.51
Jan. 31..........	1.51	1.26	1.32	.52	1.24	1.28
Feb. 7..........	1.27	1.35	1.01	.78	1.35	1.04
Feb. 14..........	1.80	1.26	1.82	.86	1.43	1.61
Feb. 21..........	2.20	1.61	1.88	.84	1.48	1.68
Total........	15.80	13.29	14.09	7.45	12.78	13.37

TABLE XIX.—*Air-dry feed*[*] *consumed in pounds per ten chicks during the week preceding the successive dates.*

Lot.	I.	II.	III.	IV.	V.	VI.
Kind of feed in excess of basal ration.	Larger amount beef scrap and protein-free feed.	Beef scrap and protein-free feed.	Cotton-seed meal and protein-free feed.	Protein-free feed.	Beef scrap.	Cotton-seed meal.
1911.						
Nov. 22..........	1.85	1.74	1.81	1.58	1.52	1.58
Nov. 29..........	2.30	2.16	2.24	1.96	1.88	1.96
Dec. 6..........	2.74	2.58	2.67	2.34	2.25	2.34
Dec. 13..........	2.74	2.58	2.67	2.34	2.25	2.34
Dec. 20..........	3.26	3.07	3.17	2.78	2.66	2.78
Dec. 27..........	3.41	3.22	3.33	2.91	2.80	2.91
1912.						
Jan. 3..........	4.05	3.82	3.95	3.46	3.32	3.46
Jan. 10..........	3.52	3.25	3.41	2.84	2.68	2.84
Jan. 17..........	4.92	4.53	4.76	3.96	3.74	3.96
Jan. 24..........	6.50	6.00	6.29	5.24	4.95	5.24
Jan. 31..........	7.04	6.49	6.81	5.68	5.36	5.68
Feb. 7..........	7.44	6.87	7.20	6.00	5.66	6.00
Feb. 14..........	8.95	8.25	8.65	7.21	6.80	7.21
Feb. 21..........	10.19	9.39	9.85	8.21	7.75	8.21
Total........	68.91	63.95	66.81	56.51	53.62	56.51

At the time of dressing the chickens of this experiment, an average-sized chick from the larger, the medium and the smaller third of each lot was set aside and not cooked, whereas the remaining chicks were cooked. The uncooked chicks were retained for the purpose of undertaking some chemical work suggested by the following ideas: It seemed possible that a liberal amount of protein in the food might lead to a reserve deposition of perhaps somewhat unorganized nitrogen compounds within or between certain cells, whereas in case of a food poor in protein, nearly all of it might be required for the organized parts of the cells. If such were the case, extraction of certain tissues with the appropriate solvent might lead to differentiations in the nitrogenous material, which could be correlated with the proportion of protein in the feed. Circumstances prevented this line of work, however, and only the weights of the giblets and the percentages of nitrogen, fat and ash in the livers were determined in these chicks. The results are given in Table XX.

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[*] A small uniform amount of mangel wurzels which was given for succulent food to each lot is not included here.

TABLE XX.—*Weight of Giblets and Percentages of Nitrogen, Fat and Ash in Livers from Large, Medium and Small Chicks.*

Lot		I.	II.	III.	IV.	V.	VI.
KIND OF FEED IN EXCESS OF BASAL RATION.		Larger amount beef scrap and protein-free feed.	Beef scrap and protein-free feed.	Cotton-seed meal and protein-free feed.	Protein-free feed.	Beef scrap.	Cotton-seed meal.
Grams of chick alive	large	1035	835	1197	582	772	825
	medium	885	722	849	435	727	730
	small	695	609	593	337	607	655
Grams of chick bled and picked	large	895	741	1049	527	681	727
	medium	770	628	743	398	627	644
	small	598	530	538	314	553	558
Grams of chick prepared for cooking.	large	672	564	783	363	498	538
	medium	582	482	540	276	466	472
	small	456	397	391	214	402	412
Grams of fresh emptied gizzard	large	30	20	44	23	32	30
	medium	29	23.	32	16	28	28
	small	20	20	27	15	27	23
Grams of fresh heart	large	5.6	4.1	6.2	3.1	2.8	4.2
	medium	4.0	5.5	5.0	2.3	3.7	3.8
	small	5.0	3.1	3.2	......	3.6	3.6
Grams of fresh liver	large	22	17	24	17	17	16
	medium	20	16	19	12	14	17
	small	16	15	14	8	12	15
Per cent. of dry matter in fresh liver.	large	26.40	27.26	27.00	25.60	26.01	26.16
	medium	25.91	26.98	26.06	26.53	26.67	25.85
	small	26.54	27.32	25.81	24.95	26.45	26.57
Per cent. of nitrogen in dry liver	large	12.47	13.10	12.83	11.40	.....	11.99
	medium	12.03	12.80	....	12.49	12.81	11.51
	small	12.76	13.32	13.35	13.41	13.41	10.89
Per cent. of fat in dry liver	large	14.39	8.41	10.10	20.55	11.44	12.59
	medium	13.48	13.33	12.91	16.93	11.16	16.01
	small	11.29	10.39	10.33	8.97	10.08	14.95
Per cent. of crude ash in dry liver	large	5.01	4.84	4.97	4.76	5.22	4.99
	medium	4.25	5.15	4.47	4.22	4.66	4.32
	small	5.91	5.05	4.80	5.09	4.90	4.58

In general, the size of the different giblets increased with the weight of the chicken, although it may be seen that there are the most exceptions to this in the case of the hearts. The only observation of any general interest in connection with the nitrogen is that usually its percentage is the largest in case of the small chicks.

In connection with the percentages of fat in the dry livers, it may be seen that the highest percentages, namely 20.6 and 16.9 were found in the livers from the large and medium chicks, respectively, of lot IV, which received an addition to the basal ration of only starch, sugar and mutton fat, and that in this particular lot the percentages decreased markedly with the size of the chicken. Where the chickens received equal amounts of nitrogen, added in beef scrap or in cotton-seed meal, but not the additional protein-free feed, the percentages of fat were less in the livers from the beef scrap lot (V) than in those from the cotton-seed lot (VI). However, in the entire cooked chicken from these same lots, the percentage of fat was higher in case of those which received the beef scrap. The average composition of all the dry livers is as follows:

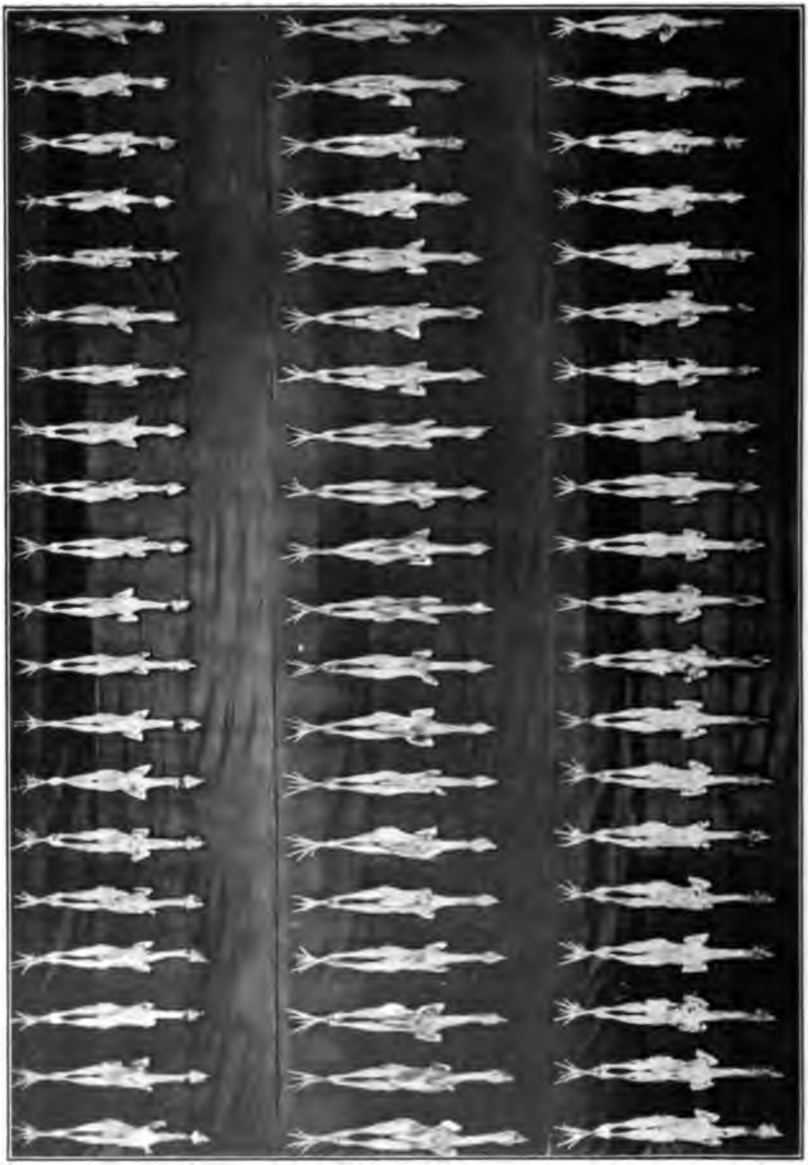
Crude ash	4.88
Fat (ether-extract)	12.63
Nitrogen	12.54
Protein, 100 minus the ash and fat	82.49 (= the nitrogen x 6.58).

The remainder of the chicks in each lot of this experiment were steamed and analyzed in the manner previously described. The results are included in Table XXI.

TABLE XXI.—*Nitrogen, Fat and Ash in Steamed Chicks.*

(The weights are given in grams per chick.)

Lot. KIND OF FEED IN EXCESS OF BASAL RATION.	I. Extra beef scrap + nitrogen-free feed.	II. Beef scrap + nitrogen-free feed.	III. Cotton-seed meal + nitrogen-free feed.	IV. Nitrogen-free feeds.	V. Beef scrap.	VI. Cotton-seed meal.
Weight, bled and picked (see fig. I)	768	656	696	412	626	658
Weight, prepared for cooking	623	542	570	322	509	530
Per cent. of dry matter in the same	33.05	33.25	33.42	32.95	31.90	30.31
Weight of dry cooked meat and soup	131.7	114.6	123.7	62.5	105.1	103.5
Weight of dry cooked bones	57.3	49.6	49.5	32.9	43.6	42.1
Weight of dry cooked total	189.	164.2	173.2	95.4	148.7	145.6
Per cent. of bones in cooked part, dry	30.3	30.2	28.6	34.5	29.3	28.9
Weight of Nitrogen in cooked meat and soup	14.11	12.20	12.51	6.45	12.18	12.50
Weight of Nitrogen in cooked bones	3.69	3.31	3.22	2.05	2.88	2.75
Weight of Nitrogen in cooked total	17.80	15.52	15.73	8.50	15.05	15.25
Weight of Fat in cooked meat and soup	39.33	33.70	37.37	20.88	26.05	21.82
Weight of Fat in cooked bones	11.77	9.39	10.30	8.84	7.41	6.27
Weight of Fat in cooked total	51.09	43.08	47.66	29.71	33.46	28.09
Weight of Crude Ash in cooked meat and soup	4.03	3.61	3.86	2.09	3.66	3.78
Weight of Crude Ash in cooked bones	20.66	17.75	16.87	10.26	16.50	16.37
Weight of Crude Ash in cooked total	24.68	21.36	20.73	12.35	20.16	20.15
Per cent. of Nitrogen in dry cooked meat and soup	10.71	10.65	10.11	10.32	11.59	12.08
Per cent. of Nitrogen in dry cooked bones	6.45	6.68	6.52	6.24	6.59	6.53
Per cent. of Nitrogen in dry cooked total	9.42	9.45	9.08	8.92	10.12	10.48
Per cent. of Fat in dry cooked meat and soup	29.86	29.42	30.21	33.40	24.78	21.09
Per cent. of Fat in dry cooked bones	20.53	18.93	20.80	26.90	16.98	14.90
Per cent. of Fat in dry cooked total	27.03	26.25	27.52	31.16	22.49	19.30
Per cent. of Crude Ash in dry cooked meat and soup	3.06	3.15	3.12	3.35	3.49	3.65
Per cent. of Crude Ash in dry cooked bones	36.04	35.80	34.09	31.22	37.80	38.90
Per cent. of Crude Ash in dry cooked total	13.06	13.01	11.97	12.95	13.55	13.84



Scale

1 ft.

Nitrogen-free food.	Cotton-seed meal.	Beef scrap.
Lot 4.	**Lot 6.**	**Lot 5.**

FIG. 1. Dressed chickens fed the same amount and kind of basal ration to which the above-mentioned feeds were added in case of the different lots. (Experiment VIII.)

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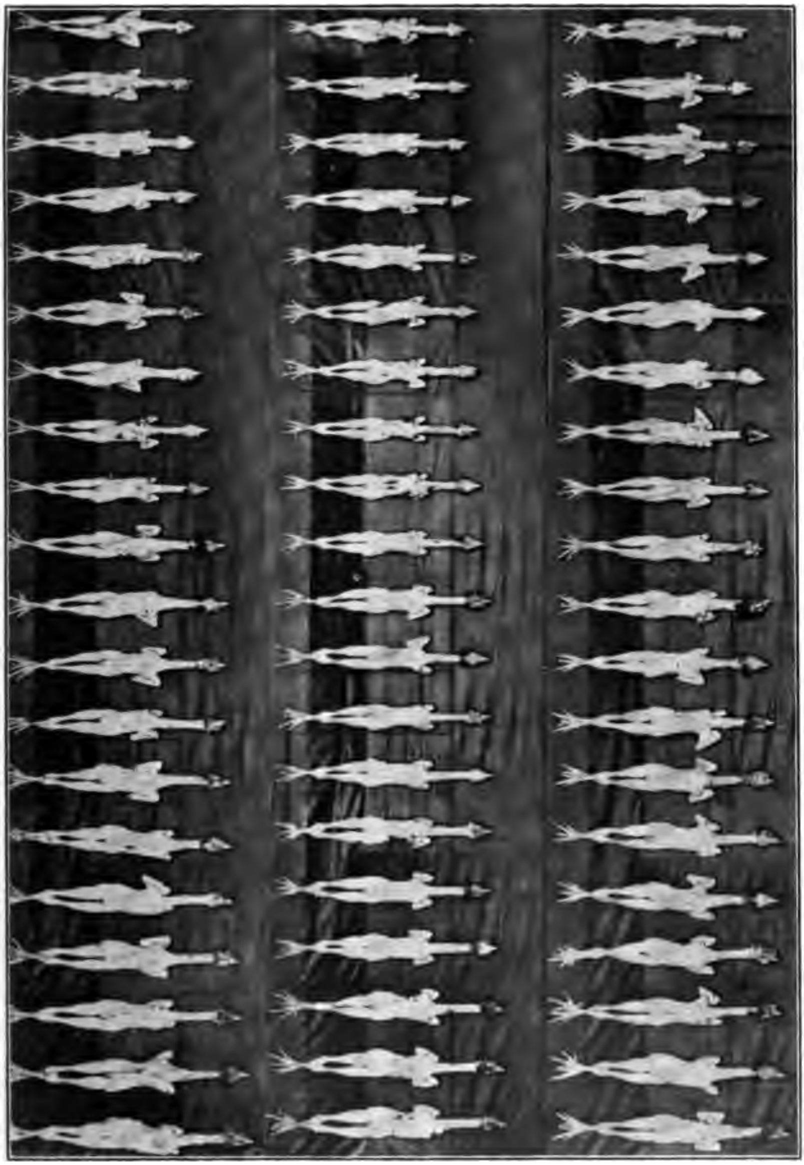

Scale
1 ft.
Cotton-seed meal and N-free food.
Lot 3.
Beef scrap and N-free food.
Lot 2.
Extra beef scrap and N-free food.
Lot 1.

FIG. 1.—Concluded.—Dressed chickens fed the same amount and kind of basal ration to which the above-mentioned feeds were added in case of the different lots. (Experiment VIII.)

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	400	2500	2600	2700	2800	2900	3000
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900 1000 1100

THE SEX AND WEIGHT OF THE INDIVIDUAL CHICKS IN EACH EXPERIMENT.

The importance to be ascribed to the average results obtained with a given lot of chicks is influenced by the number of chicks, the uniformity of the individual weights, and probably by the sex. In order that it might be possible at any time to make a more critical analysis of the experimental results than can be undertaken within the limits of the present bulletin, it has been thought desirable to record in Table XXII such data as were available concerning the individual chicks. It may be seen by reference to the table that in case of Experiments I, II and III, the individual *live* weights are given and that each dot represents *twenty* grams, whereas in case of Experiments IV, V and VII, the individual *picked* weights are recorded and each dot represents *ten* grams.

When it is observed in the table that the chicks in Experiment I were all males, it will be recalled that this was the only experiment which was begun with chicks sufficiently old so that the sex could be determined at the beginning of the experiment, and that in this case capons were used. In Experiment III it happened that there were only females at the end. The table is probably self-explanatory: it will be observed, for example, that lot 4 of Experiment II contained two males and three females, which weighed about 1,640 grams each.

OBSERVATIONS CONCERNING THE POSSIBLE TOXICITY OF THE COTTON-SEED MEAL.

In a paper, entitled "The Poisonous Principle of Cotton-seed Meal,"* Crawford recorded the toxicity of a certain extract of cotton-seed meal. An attempt was made by Philip H. Wessels, assistant in chemistry at this station, to prepare a similar extract from some of the meal used in the previously described experimental feeding; but owing to the lack of details given in Crawford's paper, it is possible that the following method of preparation, which was used, differed from that of Crawford in making the pepsin-pancreatic extract which he found to be toxic. One thousand grams of the cotton-seed meal, used in one of the feeding experiments, were mixed with 3,500 c. c. of a .05 per cent. solution of hydrochloric acid, 2 grams of powdered pepsin were then added, and the whole digested 48 hours at 30 to 40° C. It was then made very slightly alkaline with sodium hydroxid, and after the addition of 2 grams of pancreatin, was replaced in the incubator. Subsequently the liquid was squeezed from the mass, filtered, and concentrated in a vacuum oven at about 70° C. until 50 c. c. of it represented 200 grams of the original cotton-seed meal. This liquid was dark colored and viscous.

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*Jour. Pharmacol. and Expt. Ther. I, 519–48 (1910).

On September 24, 1910, some of this extract was fed to rabbits and fowls for the purpose of determining whether it was poisonous. By means of a syringe catheter, 50 c.c. were given to each of two rabbits, and 60 c.c. to each of two others. Some of the extract got into the lungs of one of the rabbits, causing death in two hours. The other rabbits remained in good health and showed no ill effects. With a syringe, 50 c.c. of the extract were given also to each of two pullets and two hens. The last special observation of the rabbits and fowls was made October 4, 1910. No harmful results appeared at any time.

During the different experiments which have been recorded, the possible toxicity of cotton-seed meal for chicks received attention, but in no case were any observations made, either in the death rate, viscera, gain in weight, or in any way, which proved that there was a toxic condition. This was in spite of the fact that the duration of certain experiments was considerable, notably Experiment I, in which capons were fed for about seven months, and Experiment II, which was continued from the termination of the records included herein until the cockerels crowed and the pullets began to lay, which occurred when they were about twenty-seven weeks old.

In Experiment III, the addition of cotton-seed meal to a well balanced ration caused a more rapid growth. Therefore, if there was any ill effect, it was masked by the advantages of the extra amount of feed.

It has been noticed repeatedly that chicks will not consume so much of a ration containing considerable cotton-seed meal as of one in which the meal has been replaced by beef scrap. It may be considered by some that this indicates an ability on the part of the chick to protect itself from consuming a toxic amount. Reference to the details of the experiment will show, however, that the amount consumed was quite large. In Experiment II the chicks were fed practically *ad libitum* between the ages of ten and twenty-four weeks, and it was found that on the average the cotton-seed meal lots consumed within twenty per cent. of those receiving the beef scrap.

FINAL WEIGHTS OF CHICKS AT DIFFERENT STAGES PRIOR TO THEIR CONSUMPTION AS FOOD.

In Experiment I, the forty-five White Wyandotte capons and "slips," which had an average drawn weight of 5.5 pounds, had lost 9 per cent. of their live weight in bleeding and picking, and 21 per cent. of their live weight upon being bled, picked and drawn.

In Experiments IV, V and VIII were obtained not only the live and dressed weight of three different breeds, but the weight as prepared for cooking. Furthermore, the dry matter of the entire edible portion was determined.

The data are summarized in Table XXIII.

TABLE XXIII.—*Average weight in pounds per ten chicks in different conditions, and the percentage of loss in passing from one condition to another.*

	Low-protein lots.	Medium-protein lots.	High-protein lots.
Number of lots included	4	8	3
Live weight	9.50	16.30	19.10
Dressed weight (bled and picked)	8.91	14.71	16.70
Weight prepared for cooking	5.95	10.75	12.26
Dry matter of edible portion after cooking	1.50	2.60	2.96
Per cent. of live weight lost in dressing	6	10	13
Per cent. of live weight lost in dressing and preparing for cooking	37	34	36
Per cent. of live weight composed of dry edible matter	16	16	16
Per cent. of dressed weight lost in preparing for cooking	33	27	27
Per cent. of dressed weight composed of dry edible portion	17	18	18

The greater percentage loss from bleeding and picking, which was correlated with the increase in protein, was doubtless due to a larger growth of feathers which this ingredient stimulated. It was noticed that the low-protein lots were frequently quite bare of feathers.

In obtaining the edible portion, the bones were carefully removed by hand from the warm, steamed chickens. Probably less meat was left with the bones than is usually the case in family consumption. The skin, heart, liver, kidney, and muscular portion of the gizzard, as well as the broth were included in the edible portion, although in many cases some of these are not eaten. Even when all are included it may be seen that only about a sixth of the dressed weight is represented in the edible portion when all of the water is eliminated. In other words, the dry matter of the edible portion would cost over two dollars a pound, provided the dressed broilers could be purchased at 35 cents per pound. On a similar basis the fresh edible portion, which is about seven-tenths water, would cost about sixty-five cents per pound.

THE NUTRITIVE RATIO OF THE FEEDS.

Although nutritive ratio is strictly the ratio of the digestible protein to the sum of the digestible fat multiplied by about 2.3, and the digestible fiber and nitrogen-free extract matter, in connection with the present experiments it has been considered as the ratio of the protein to the sum of the fat multiplied by 2.3, and the nitrogen-free extract matter. [Protein : (Fat × 2.3) + nitrogen-free extract]. That is, the digestibility has not been taken into consideration, and the fiber has not been included, in these calculations. This course has been adopted because of the probable low feeding value of the fiber for chicks and also the paucity of information concerning the digestibility for poultry of the other constituents.

It has been customary to ascribe considerable importance to nutritive ratio, but there are certain reasons why less attention will probably be paid to this ratio in the future. It is now recognized that the value of a feed depends not only upon the amount which is digestible, but also upon the amount of energy used up in the process of comminution and digestion.

Furthermore, the price of the best protein and non-protein vegetable concentrates is not so very different at the present time. Therefore, it becomes less necessary to conserve the protein by replacing it with carbohydrates and fat to the fullest extent. An excess of protein above the necessary nitrogen requirements may serve in the same capacity as starch, for example, for energy purposes; and unless some disadvantage arises from the elimination of the waste products of the excess protein, there may be a wide variation in the proportion of this ingredient, and, consequently, in the nutritive ratio, provided there is no deficiency of nitrogen in the feed.

A deficiency of protein as a source of nitrogen cannot of course be overcome by an excess of the other feeding ingredients, whereas the latter may to a certain extent be replaced by an excess of protein. The growth of young animals may be very much retarded, therefore, by limiting the amount of protein. Within certain limits, the necessary amount of protein may be secured by liberal feeding of even a ration having a wide nutritive ratio, although the process may not be economical, owing to the waste of carbohydrates and fat. If the proportion of non-protein substances is too large, then the body may not be able, because of the limited capacity of the digestive organs, to utilize sufficient food to supply the protein requirements for the most efficient rate of growth possible.

Certain of the experiments described in the present bulletin afford an opportunity for correlating different nutritive ratios with the growth of chicks.

Experiment II (page 231) showed that during the first four weeks the live weights of chicks receiving the cotton-seed meal increased successively with the nutritive ratios of 1:3, 1:4 and 1:5, whereas the reverse was true with those receiving beef scrap as the chief protein concentrate. The ratios were widened by partly replacing the protein concentrates by corn meal.

During the last fourteen weeks of the same experiment the ratios were widened to 1:4, 1:5 and 1:6. On a given amount of feed the cotton-seed meal lots reached a live weight per ten chicks of 26.74, 29.06 and 29.21 pounds, respectively, with the widening of the nutritive ratios; and, similarly, the beef scrap lots which consumed a larger amount of feed, weighed 35.31, 36.70 and 36.00. Apparently the protein requirements were supplied in all cases, and the excess in case of the narrower ration affected practically only those which received a considerable substitution of cotton-seed meal in place of corn meal. This substitution resulted in a less ready consumption of the feed and in smaller gains. The kind of the protein concentrate seemed more important than the nutritive ratio. It should be remembered, however, that in this experiment there proved to be a smaller proportion of cockerels in the lots on the narrowest nutritive ratio than in the others, which fact may have had something to do with the smaller weights.

In a number of the experiments which have been described, the different lots represented in a given experiment were fed the same amount of a basal ration containing a variety of feeds, as well as a liberal amount of bone meal to furnish abundant calcium phosphate. Although it was desired to supply in the basal ration only a small proportion of protein, the presence of even small amounts of the wide variety of feeds resulted in a basal mash with a nutritive ratio usually about 1:5. This ratio was markedly widened by giving a scratch feed composed of cracked corn and rice, which had a nutritive ratio of about 1:9.5. Equal weight parts of the basal mash and scratch feed were most frequently fed, resulting in an entire basal ration having a nutritive ratio of about 1:7.

In the case of those lots which received an equal additional amount of nitrogen, it was usual to add beef scrap at the rate of from 30 to 36 per cent. of the basal mash, and cotton-seed meal at the rate of 40 to 50 per cent. This addition of beef scrap narrowed the nutritive ratio of the entire feed to about 1:4, which was a little narrower than that caused by the addition of the cotton-seed meal.

When a still larger amount of the beef scrap was supplied for the purpose of producing more rapid gains, a 50 per cent. addition to the basal mash was frequently made, thereby reducing the nutritive ratio of the entire feed to nearly 1:3.

Chicks about four weeks old, which were continued on these rations for about fifteen weeks (Experiments IV, V and VIII), all lots having received the same amount of the *basal* ration, attained an average live weight per ten chicks about as follows: On only the basal ration, 9.6 pounds; when this was supplemented with the smaller addition of beef scrap, or with the same addition of nitrogen in cotton-seed meal, 16.1 pounds; and with the larger addition of beef scrap, 19.1 pounds.

By supplementing the basal ration with the protein-free feeds (starch, sugar and cotton-seed oil, or mutton fat), the nutritive ratio was widened from 1:7 to 1:8.5, and the live weight was practically unchanged, even when the chicks had 25 per cent. more feed. (Experiment IV.)

In Experiment VIII, by supplementing, with starch, sugar and mutton fat, the rations to which an equal amount of nitrogen was added in beef scrap or in cotton-seed meal, the nutritive ratio was increased from about 1:3.6 to 1:4.8, resulting in somewhat fatter chicks.

In the experiments to which reference has just been made it is obvious that growth depended mainly upon the amount of protein, and that the quantity of the other ingredients of the basal ration was so liberal that even an extra amount of feed in the form of carbohydrates and fat, although materially changing the nutritive ratio, left the live weight of the chicks practically unchanged. It is true, however, that the amount of the fat in the chicks was somewhat increased. For the rapid growth of young chicks it is more important within reasonable limits that the *amount* of protein be sufficient than that it be associated with a definite proportion of carbohydrates and fat; or, in other words, that there be a definite nutritive ratio. It would not be *economy,* however, to supply carbohydrates and fat so liberally that the chicks could make no good use of them.

On account of the fact that protein is not only a source of nitrogen, but also of energy, a feed with an excess of protein and an unnecessarily narrow nutritive ratio may nevertheless fulfil all the requirements for rapid growth.

THE RELATIVE EFFECT OF EQUAL AMOUNTS OF NITROGEN IN BEEF SCRAP AND COTTON-SEED MEAL ON THE FINAL WEIGHT OF CHICKS.

Experiments at this station have shown that when beef scrap and cotton-seed meal are each added to a common basal ration so as to furnish an equal *proportion* of nitrogen, and the chicks are given all they will eat, they will consume more of the beef scrap ration than of the cotton-seed meal ration, and make a more rapid growth. This was true, even when the cotton-seed meal ration was supplemented by ash constituents so that the latter were similar to those in the beef scrap ration.

In most of the experiments described in the present bulletin, the lots of a given experiment were limited to a uniform amount of the basal ration, to which beef scrap and cotton-seed meal were added so that each concentrate furnished an equal *amount* of nitrogen in those cases where the two concentrates were especially compared.

It is believed that the basal rations were so liberally supplied with non-nitrogenous constituents that the addition of more of these in the protein concentrates had at most only a minor influence upon the growth, but that the latter was determined mainly by the nitrogenous constituents, which in every case now under consideration were shown to be below the optimum requirements for the greatest amount of growth.

In making a comparison between the two concentrates on an equal nitrogen basis, the reader should keep clearly in mind the fact that even if one of them caused a larger growth, the larger chickens thereby produced did not get a correspondingly larger amount of feed. It seems, however, that under the conditions of these experiments any increase in growth caused by one concentrate over another can be considered as an approximate measure of the additional efficiency of that concentrate as a source of protein.

To enable a ready comparison of growth, the relations of the average weights of the cotton-seed meal lots to 100 as representing the weights of the beef scrap lots which received an equal amount of nitrogen, are recorded below:

Expt.	Alive.	Bled and picked.	Prepared for cooking.	Cooked, water-free.
I	94	91	......	......
IV	91	99	89	86
V	117	116	109	107
VI	92	......	......	......
VII	90	......	......	......
VIII*				
a	102	105	104	98
b	107	108	105	105
Average of the above	99	104	102	99

It is evident that, although in the individual experiments there are differences one way or the other, practically no difference resulted in the average of the combined weights whether beef scrap or cotton-seed meal was used to furnish an equal amount of nitrogen.

THE EFFECT OF THE ADDITION OF THE PROTEIN-FREE FOODSTUFFS.

Certain of the experiments afford an opportunity for noting the effects of protein-free feeds such as starch, sugar, cotton-seed oil and mutton fat. In Experiment IV, the basal ration was in case of one lot supplemented with the first three of these, but with practically no effect upon the weight of the chicks as prepared for cooking. The amount and percentage of dry matter in the chicks so prepared, however, was somewhat greater in case of those fed with the extra protein-free feed, although the total nitrogen was not increased. The principal difference was in the fat, the percentage in the dry cooked portion being 29.7 in the case of the chicks which were fed only the basal ration, and 36.3 in case of those which received the additional protein-free food. The total amount of fat per ten cooked chicks was similarly increased from 267 to 351 grams. (See page 240 for the analytical results).

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*a refers to the lots which received no extra protein-free feed, and *b* to those which did receive an extra amount.

In Experiment VIII the effect of the protein-free feed was determined when it supplemented rations containing much more protein than in case of Experiment IV, on which account it might be expected to be of more service in promoting growth. The average data of the two lots which received the same amount of protein, in one case in cotton-seed meal and in the other in beef scrap are stated in the first of the following columns; and the average of the two lots which differed only in that they received about 20 per cent. additional food as sugar, starch and mutton-fat is given in the second column.

	Without extra protein-free feeds.	*With* extra protein-free feeds.
Weight per chick, as prepared for cooking, grams.....	519	556
Water-free weight of the same when cooked, grams..	147	169
Per cent. of dry matter as prepared for cooking.....	28.3	30.4
Weight of fat per cooked chick—		
In meat and soup, grams....................	23.9	35.5
In bones, grams..........................	6.8	9.9
Per cent. of fat in water-free, cooked chicks........	20.9	26.8
Per cent. of nitrogen in water-free, cooked chicks....	10.30	9.27
Weight of nitrogen per cooked chick—		
In meat and soup, grams....................	12.3	12.3
In bones, grams..........................	2.8	3.3

It may be seen that the addition of the protein-free feeds was accompanied in this case by some increase in the amount of dry matter, and that the major part of this increase was fat. The nitrogen in the edible portion was not increased, what little increase in nitrogen there was being confined to the bones.

Owing to the fact that there proved to be a much larger proportion of cockerels in the lots receiving the addition of protein-free feeds, attention to small differences may not be warranted.

In Experiment VIII, the percentage of fat in the dried livers of a large, medium and small chicken from each lot was no greater in the somewhat fatter chickens which received the addition of the protein-free foodstuffs than in those which did not.

THE RELATION OF THE NITROGEN RECOVERED IN THE COOKED CHICKS TO THAT CONSUMED IN THE FEED.

At the termination of Experiments IV, V and VIII the chickens were analyzed, thus making possible a comparison of the amount of nitrogen in the cooked chickens with the amount consumed in the feed from the beginning of the experiments when they were about four weeks old. To obtain the approximate amount of nitrogen in chicks at the latter age, the following data was secured concerning four individuals:

	I.	II.	III.	IV.	Avg.
Live weight of chicks in grams....	90.5	91.7	100.1	109.3	97.9
Weight when prepared as for cooking, grams.................	51.3	48.4	58.0	60.0	54.4
Grams of nitrogen in chick prepared as for cooking........	1.468	1.430	1.655	1.759	1.578

The average amount of nitrogen will be deducted in each case from that found in the cooked chicks at the end of the experiment, in ascertaining the relationship between the amount of nitrogen fed and that recovered in the cooked chicks.

When only the low-protein basal ration itself was fed (Experiment IV, lots I and V) the average chick received during the experiment 42.47 grams of nitrogen and contained, in the cooked portion, 7.82 and 8.26; average, 8.04 grams. If from this average is subtracted 1.58, the amount of nitrogen in the corresponding part of the young chicks, there remain 6.46 grams, which represent a recovery in the cooked portion of 15.2 per cent. of the nitrogen given in the feed; the corresponding relation in case of another lot in the same experiment, which received in addition to the basal ration only the protein-free food, was 14.6 per cent. In Experiment V, the similar lot received per chick, 42.11 grams, from which there was a net recovery of 13.8 per cent.; and again, in Experiment VIII, it received 39.87 grams, from which there was a net recovery of 17.4 per cent.

The recovery per chick in case of those lots which received an additional equal amount of nitrogen in beef scrap and cotton-seed meal is shown by the following table:

	Grams of nitrogen in the entire feed.	Grams of nitrogen in an average cooked chicken.		Per cent. of nitrogen recovered per cooked chick after deducting that in a young chick.	
		Beef scrap lots.	Cotton-seed meal lots.	Beef scrap lots.	Cotton-seed meal lots.
Expt. IV, lots III, II	80.6	17.20	13.73	19.4	16.8
Expt. V, lots II, III	77.8	13.68	15.57	15.6	18.0
Expt. VIII, lots V, VI	75.3	15.05	15.25	17.9	18.2
Expt. VIII, lots II, III	75.6	15.52	15.73	18.4	18.7
Average	77.3	15.36	15.07	17.8	17.5

The chicks were also analyzed in case of two lots which received in beef scrap a still larger amount of nitrogen than in the cases just mentioned. To lot IV, Experiment IV, 98.3 grams per chick were fed and after deducting 1.58 grams as usual, 16.1 grams or 16.4 per cent. were recovered. Similarly in the case of lot I, Experiment VIII, 99.2 grams were fed and the net recovery was 16.2 grams, or 16.3 per cent. It may be seen that the percentages of nitrogen recovered from the rations receiving the larger amount of beef scrap were less than from the otherwise corresponding lots which received a smaller amount, for in the latter case, 19.4 and 18.4 per cent., respectively, were recovered. It is not improbable that in case of the rations containing the larger amount of beef scrap, more nitrogen was fed than was necessary for the maximum rate of growth, and hence it was not used so economically.

It may also be observed that the chicks receiving the very limited amount of nitrogen present in the basal ration, and making very small gains because of that fact, did not retain so large a proportion of the nitrogen in the part used for cooking, as did those receiving an amount of protein which enabled them to make a more normal growth.

If it be conceded that the amount of nitrogen recovered in the cooked chicks which received only the basal ration was the same as recovered from the same ration when associated with the additions of the protein concentrates, the difference between the amount of nitrogen in the cooked chicks produced under these two conditions may be attributed to that given in the supplementary protein concentrates.

The data are arranged from this standpoint in the following table, in which the nitrogen recovered in the cooked chicks from the protein concentrates themselves is considered to be the difference between the nitrogen in the cooked chicks which received only the basal ration and in those receiving also beef scrap or cotton-seed meal.

	Grams of nitrogen per cooked chicken.			Grams of nitrogen recovered from the concentrate.		Grams of nitrogen added in each concentrate.
	Beef scrap lots.	Cotton-seed meal lots.	Basal ration lots.	Beef scrap.	Cotton-seed meal.	
Expt. IV	17.20	13.73	7.95	9.25	5.78	38.1
Expt. V	13.68	15.57	7.40	6.28	8.17	35.8
Expt. VIII, *a*[*]	15.05	15.25	8.50	6.55	6.75	35.7
b	15.51	15.73	8.50	7.01	7.23	35.7
	61.44	60.28	32.35	29.19	27.93	145.3

One would hesitate to conclude from the foregoing results that the protein in one of the concentrates was a superior source of nitrogen to that in the other. About a fifth of the nitrogen fed in the protein concentrates was recovered in the cooked chick. When considering the preceding table the following facts should be remembered, namely, that the feed was so given that all lots in an experiment ate the same amount of the basal ration, that the supplements to this ration constituted that much additional feed, and that the amount of feed was limited by the lot of chicks which ate its food least readily, and which was allowed to eat *ad libitum*.

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[*] *a* refers to the lots which did not received extra non-protein feeds, and *b* to those which did.

THE RELATION OF THE GAIN IN LIVE WEIGHT TO THE NITROGEN CONSUMED IN THE FEED.

In only three of the experiments was the nitrogen determined in the cooked chicks at the end of the feeding period, in order that there might be obtained a measure of the efficiency of the nitrogen fed in cotton-seed meal and in beef scrap.

It is possible, however, to gain some idea of the relative efficiency of the nitrogen in the two concentrates by noticing the relation between nitrogen fed in rations containing these concentrates, and the gain in live weight. Especially is this true whenever the amount of protein fed was sufficiently small for it to become the principal factor which controlled the growth.

Certain data are presented in Table XXIV for the purpose of making the above-mentioned comparisons. On account of the difference in the age of the chicks, it is not always appropriate to compare the results of one experiment with those of another, but a strict comparison is justifiable between certain lots of a given experiment.

In Experiment I it is probable that at least for a part of the time lots I and II received less protein than was necessary for maximum growth, as indicated by the slightly greater average weekly gain made by lot III, which received more protein. It may be seen by reference to the table, that lot II, which received slightly less nitrogen in beef scrap per a given live weight than lot I which was given cotton-seed meal, made a greater gain per gram of nitrogen fed.

A very liberal amount of protein was fed in Experiment II, and it is not probable that this ingredient was deficient in case of any of the lots. An idea of the liberality of the protein feeding may be gained by comparing the average amount of nitrogen fed per 100 grams of chick in this experiment (3.16 grams) with the similar value for "lots V and VI" and "lots VI and V" of Experiment VI (1.13 grams). This comparison is fairly justifiable for the average age of the chicks was about the same even though the duration of the experiments was different. It may be seen that the larger consumption of protein in this experiment did not result in much greater gains and that the gain in weight per gram of nitrogen fed was less in Experiment II than in any other experiment. Although it is plain that a deficiency of protein was not the main factor which controlled the growth in case of this experiment, it is of interest, nevertheless, to compare the results with rations containing the same amount or the same proportion of nitrogen in the two concentrates. It should be recalled that there were three different nutritive ratios in case of each concentrate, and that the feeds were in this instance, not in all cases limited to an equal nitrogen basis. However, by reference to the last column in the table, it will be seen that lots I and IV happened to receive the same amount of nitrogen per chick, and that lots III and VI also received nearly the same amount per chick. In both of these comparisons it may be seen that the "gain per gram of nitrogen fed" was greater in case of the beef scrap lots. It may also be observed that the "nitrogen fed per 100 grams of chick" was only 1 per cent. greater for lot VI than for lot V, whereas the "gain per gram of nitrogen fed" was 9 per cent. greater in case of the former or beef scrap lot. Again, beef scrap lot VI received a little less nitrogen per 100 grams of chick than cotton-seed meal lot III and yet it made a larger gain.

In Experiment IV, the beef scrap lot III consumed the same amount of nitrogen per chick and a little less per 100 grams than the cotton-seed meal lot II, and yet made considerably more gain. The reverse is seen to be true when a similar comparison is made between lots II and III of Experiment V, for in that case the gain was greater in case of the cotton-seed meal lot.

In Experiment VI the gain per gram of nitrogen fed was more with the beef scrap lot (VI, 1st half) than with the cotton-seed meal lot (V, 1st half) for the first fifteen weeks of the experiment. For the remaining eleven weeks, during the first week of which a reversal of the concentrates was affected, the gain for the lot then receiving beef scrap (V, 2nd half) was less than that for the lot then receiving

TABLE XXIV.—*The Relation of the Average Weekly Gain to a Gram of Nitrogen Fed.*

Experiment.	Lot.	Age of Chicks, Weeks.			Length of experiment, weeks.	Average Live Weight at End.			Coefficient of variation of average total gains.	Average of weekly live weights.	Average of weekly gains.	Weekly gain per 100 grams of chick.	Nitrogen fed per 100 grams of chick.	Gain per gram of nitrogen fed.	Principal protein concentrates in ration.†	Average approximate amount of nitrogen fed per chick per week.
		Initial.	Final.	Average.		Average weight.	Probable error.	Standard deviation.								
						Grams.	Grams.	Grams.+	Grams.±	Per ct.±	Grams.	Grams.	Grams.	Grams.		Grams.
I	1	15	45	30	30	3084.4	51.3	294.20	12.02	1867.1	82.51	4.419	.907	4.873	C. S.	16.7
	2					3260.7	52.5	301.42	11.40	1938.8	88.74	4.577	.855	5.350	B. S.	16.7
	3					3333.9	70.6	404.93	15.19	2020.3	91.58	4.533	.923	4.911	B. S.	18.6
II	1	6	24	15	18	1241.1	29.1	187.78	17.77	639.9	57.15	8.931	3.515	2.541	C. S.	22.5
	3					1328.5	30.8	204.29	17.77	669.2	63.28	9.455	2.862	3.304	C. S.	19.2
	5					1327.3	35.8	237.04	20.92	694.6	62.82	9.044	2.380	3.800	C. S.	16.5
	2					1620.2	40.0	258.79	18.06	846.7	78.57	9.280	3.123	2.971	B. S.	26.4
	4					1665.0	32.5	215.20	14.55	840.9	82.13	9.767	2.677	3.648	B. S.	22.5
	6					1593.3	40.2	266.45	18.95	807.0	80.34	9.955	2.407	4.136	B. S.	19.4
III	1	3	16	9½	13	723.9	32.6	128.02	20.35	333.0	48.67	14.619	1.716	8.519	B.	5.7
	2					848.8	15.2	63.72	8.47	362.0	58.10	16.049	2.386	6.727	B. + C. S.	8.6
IV*	1	4	19	11½	15	408.8	15.2	84.31	25.96	242.0	22.08	9.120	1.175	7.759	B.	2.8
	2					688.8	26.0	139.00	22.98	341.7	38.86	11.372	1.314	8.657	B. + C. S.	4.4
	3					692.8	20.6	105.77	17.35	351.2	43.18	12.295	1.223	10.052	B. + B. S.	4.4
	4					776.1	24.6	146.11	21.14	397.4	50.68	12.755	1.334	9.558	B. + B. S.	5.3
	5					409.5	16.5	94.93	29.08	229.9	21.77	9.471	1.238	7.653	B.	2.8
	6					421.8	19.7	101.32	30.08	237.8	21.41	9.003	1.273	7.073	B. + C.	3.0
V*	1	3	18	10½	15	376.0	12.0	68.96	22.39	213.1	22.83	10.716	1.333	8.038	B. + C.	2.8
	2					591.8	29.2	149.71	27.94	306.6	41.55	13.550	1.688	8.027	B. + B. S.	5.2
	3					756.2	18.3	85.69	12.52	326.0	48.17	14.776	1.591	9.285	B. + C. S.	5.2
	4					737.0	39.4	193.84	28.59	360.5	53.49	14.839	1.591	9.323	B. + B. S.	5.7

*In experiments IV and V, the average weight probable error, standard deviation, and coefficient of variation are calculated on *individual* picked and bled weights as usual, the gains being based on live weights.

NOTE.—For an explanation of the significance of the standard deviation, coefficient of variation and probable error, the reader is referred to C. B. Davenport's "Statistical Methods," and for an especially clear and concise explanation to pages 467–480 of Bulletin 165 of the University of Illinois Agricultural Experiment Station on "The Element of Uncertainty in the Interpretation of Feeding Experiments."

†B=Basal ration (Mash and Scratch Feed.) C. S.=Cotton-seed meal. B. S.=Beef Scrap. C.=Non-protein addition of carbohydrates and fats.

TABLE XXIV.—Concluded.—*The Relation of the Average Weekly Gain to a Gram of Nitrogen Fed.*

Experiment.	Lot.	Age of Chicks, Weeks.			Length of experiment, weeks.	Average Live Weight at End.			Coefficient of variation of average total gains.	Average of weekly live weights.	Average of weekly gains.	Weekly gain per 100 grams of chick.	Nitrogen fed per 100 grams of chick.	Gain per gram of nitrogen fed.	Principal protein concentrates of ration.†	Average approximate amount of nitrogen fed per chick per week.
		Initial.	Final.	Average.		Average weight.	Probable error.	Standard deviation.								
						Grams.	Grams. +	Grams. +	Per ct. +	Grams.	Grams.	Grams.	Grams.	Grams.		Grams.
VI	5 1st half	3	18	10½	15	707.6				311.8	41.37	13.267	1.738	7.633	B. + C. S.	5.4
	6 2nd half	18	29	23½	11	1695.5				1263.4	89.81	7.109	.942	7.547	B. + C. S.	11.9
	5 and 6 combined	3	29	16	26					714.4	61.86	8.659	1.142	7.580	B. + C. S.	8.1
	6 1st half	3	18	10½	15	767.0				353.4	45.24	12.802	1.522	8.413	B. + B. S.	5.4
	5 2nd half	18	29	23½	11	1701.0				1245.4	84.91	6.818	.952	7.161	B. + B. S.	11.9
	6 and 5 combined	3	29	16	26					730.8	62.02	8.487	1.111	7.639	B. + B. S.	8.1
VII	1	3	18	10½	15	771.1				332.1	44.76	13.477	1.546	8.716	B. + C. S.	5.1
	2					776.1				308.8	44.88	14.534	1.686	8.620	B. + C. S.	5.2
	3					765.7				285.3	44.12	15.464	1.769	8.740	B. + C. S. ‡	5.
	4					860.0				310.5	50.62	16.305	1.895	8.602	B. + B. S.	5.9
VIII	1	4	18	11	14	876.1	20.0	139.18	18.21	403.6	55.01	13.630	1.741	7.828	B. + B. S. + C.	7.0
	2					749.6	18.6	135.01	21.21	358.6	46.14	12.865	1.487	8.653	B. + B. S. + C.	5.3
	3					798.7	32.4	245.13	35.75	360.4	49.64	13.774	1.482	9.293	B. + C. S. + C.	5.3
	4					467.0	14.8	107.65	30.32	251.2	25.66	10.215	1.125	9.083	B. + C.	2.8
	5					710.9	12.5	82.54	13.78	342.4	44.45	12.981	1.552	8.366	B. + B. S.	5.3
	6					755.4	13.2	99.58	15.48	351.2	45.59	12.981	1.516	8.563	B. + C. S.	5.3

NOTE.—For an explanation of the significance of the standard deviation, coefficient of variation and probable error, the reader is referred to C. B. Davenport's "Statistical Methods," and for an especially clear and concise explanation to pages 467–480 of Bulletin 165 of the University of Illinois Agricultural Experiment Station on "The Element of Uncertainty in the Interpretation of Feeding Experiments."

†B=Basal ration (Mash and Scratch Feed.) C. S.=Cotton-seed meal. B. S.=Beef Scrap. C.=Non-protein addition of carbohydrates and fats. ‡Baked.

cotton-seed meal (VI, 2nd half), although for the entire experiment beef scrap apparently produced a slightly greater gain per gram of nitrogen fed.

In Experiment VII, the beef scrap lot was allowed to have more nitrogen than the cotton-seed meal lots, and it made a greater average weekly gain, but the gain per gram of nitrogen fed was not more.

In Experiment VIII, the gain per gram of nitrogen fed was more with the cotton-seed meal lots than with the beef scrap lots, whether the concentrates were or were not supplemented with an extra amount of nitrogen-free food.

It will be observed that in the greater number of instances, there was a larger gain in live weight per gram of nitrogen fed in case of the beef scrap rather than the cotton-seed meal lots.

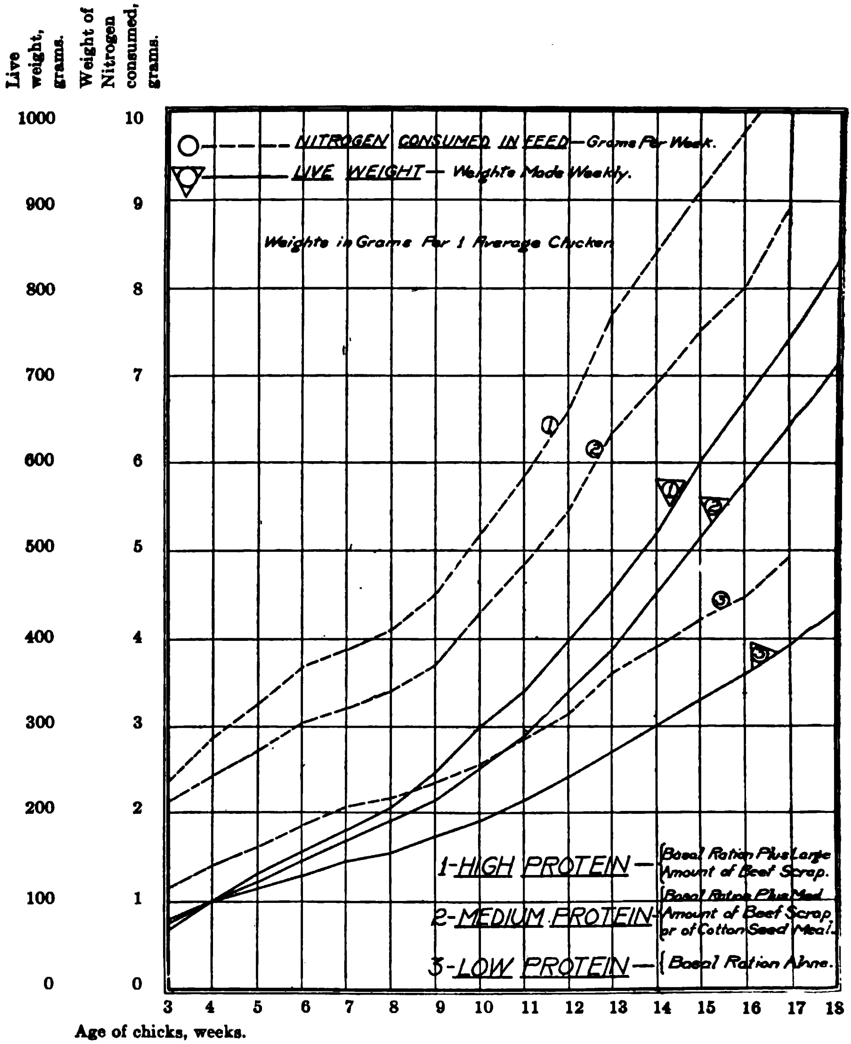
The conditions were so different in a number of the experiments that it seems hardly justifiable to record the average relative difference in the returns from feeding the two concentrates, especially as the results are not uniformly favorable to either one of them, but rather to invite consideration of the individual comparisons in the light of the specific conditions affecting each individual experiment as detailed previously.

Experiments IV, V, and VIII each contained lots which received only the protein of the basal ration (low protein), those which received an additional amount of protein in either cotton-seed meal or beef scrap (medium protein), and those which had an extra addition of beef scrap (high protein). Inasmuch as the chicks in the three experiments were of about the same age and were fed similarly, the nitrogen consumed and the live weight for each individual week have been charted in Figure II. The low protein curves represent the average of one lot from each experiment, which received protein only in the basal ration. The medium protein curves represent the mean between the average for the three lots which received an addition to the basal ration of only cotton-seed meal and the three which received only beef scrap furnishing the same amount of protein as in the cotton-seed meal. The high protein curves represent the average of the three lots receiving the extra amount of beef scrap.

The parallelism between the number of grams of nitrogen consumed (broken line) per 100 grams of live weight (solid line) is readily observed in the case of each of the three planes of protein nutrition.

It may be seen that the amount of nitrogen fed in relation to the live weight was, in the case of the medium and high protein rations, relatively high during the first few weeks of the experiment. Since this did not result in much greater gains in live weight, it seems probable that the proportion of protein was unnecessarily high for such young chicks, there being more than two grams fed per 100 grams of live weight.

FIG. II.—Relation between nitrogen consumption and live weight at *different ages of* chickens grown on different planes of protein nutrition.



NOTE: The amount of nitrogen indicated as being consumed when the chicks were of a given age refers to that received during the succeeding week.

SUMMARY.

This bulletin contains the results of eight experiments which conclude the study of the value of different protein concentrates for the growth of chicks. Abstracts from the earlier, unavailable bulletins on the subject are also included.

The work described herein was confined to a comparison of only the two protein concentrates, beef scrap and cotton-seed meal. In most cases they were fed on an equal nitrogen basis, and the mash including the cotton-seed meal was always consumed the least readily.

A pepsin-pancreatin extract made from one of the lots of cotton-seed meal had no harmful effect upon rabbits and hens to which it was fed, and in no case were any observations made which proved that there was a toxic condition resulting from feeding cotton-seed meal as a supplement to a basal ration.

The basal ration in such cases was so deficient in protein that a considerable amount of this ingredient could be added in the concentrates without supplying enough for the maximum growth of the chicks. Under such conditions the amount of protein would be the main factor influencing growth. Furthermore, the non-protein constituents of the feeds were usually in such liberal amounts that the protein was probably mainly efficient as a source of nitrogen rather than as a source of energy.

It was demonstrated by the results with certain rations that for the growth of young chicks it is more important within reasonable limits, for the amount of protein to be sufficient than that it be associated with a definite proportion of carbohydrates and fat; or, in other words, that there be a definite nutritive ratio.

In certain of the experiments, the chicks were cooked after preparation in the usual way, and the amount of water, ash, protein and fat determined not only in the bones, but also in the meat and soup. In one case the livers were analyzed separately.

Between the ages of about four to fifteen weeks, the chicks retained in the cooked portion about eighteen per cent. of the nitrogen consumed during that period in the medium-protein rations in which case there was no unnecessary waste of nitrogen.

Together with the other data, the gain in live weight per gram of nitrogen consumed is recorded for all of the experiments. In the greater number of instances, there was a larger gain in live weight per gram of nitrogen fed, in case of the beef scrap rather than the cotton-seed meal lots. The conditions are so different, however, in a number of the experiments, that it seems hardly justifiable to record the average relative difference in the returns from feeding the two concentrates, but rather to urge a consideration of the results of the individual experiments in the light of these conditions.

If the constituents of bone are supplied, there appears to be no reason why cotton-seed meal may not be used to furnish a considerable portion of the protein required by chicks, especially if a moderate consumption of food is satisfactory to the feeder. If the most rapid growth is desired, regardless of the amount of feed consumed, beef scrap will be found more satisfactory since the chicks consumed more of the beef scrap ration when allowed to have all they would eat and made a more rapid growth in consequence. When limited to the same amount of nitrogen, however, the gains were not very different whether cotton-seed meal or beef scrap formed a prominent part of the rations.

Studies on Fowl Cholera: III. The Inheritance in Rabbits of Immunity to Infection with the Bacterium of Fowl Cholera.

BULLETIN 157

Agricultural Experiment Station

OF THE

Rhode Island State College

KINGSTON, R. I., U. S. A., APRIL, 1914.

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AGRICULTURAL EXPERIMENT STATION OF THE RHODE ISLAND STATE COLLEGE.

BULLETIN 158.

STUDIES ON INHERITANCE IN PIGEONS: I. HEREDITARY RELATIONS OF THE PRINCIPAL COLORS.*

BY LEON J. COLE.

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*Contribution 206 from the Agricultural Experiment Station of the Rhode Island State College; papers from the Department of Experimental Breeding of the Wisconsin Agricultural Experiment Station, No. 2.

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INTRODUCTION.

The studies described in the present paper were begun at the Rhode Island Agricultural Experiment Station early in the year 1907. They were undertaken primarily to discover whether the decisive results which had already at that time been obtained with respect to the inheritance of definite unit characters in mammals, especially in the color of the coat, applied as well to birds, and to compare the results obtained with the work which had been done with fowls and canaries. The investigations on these other birds had not given in general such clear-cut and definite results as those with the mammals. In the case of the fowls, this was undoubtedly in large part due to the complications introduced by color patterns, especially patterns resulting from the diversified coloration and markings of individual feathers. Pigeons seemed especially suitable for such a study, since they not only occur in a considerable variety of colors, but in most of these it is possible to obtain varieties of good self color, not complicated by any special pattern.

In most of the inheritance studies on poultry, birds of widely different breeds, differing markedly in a large number of characteristics, have been crossed, introducing in this way a confusing complexity of characters into the offspring. It seemed that a more intensive method, concentrating in a few well-defined differences within the same breed, might lead to results which would be obscured by the multitude of differing characters present in birds of different breeds. Furthermore, it seemed less probable that characters presenting the same objective appearance would behave differently in inheritance within a single breed. Thus for example we have in different breeds of fowls both the dominant and recessive white plumage. While it is desirable that all characters of this kind should ultimately be investigated, it simplifies matters if, in the beginning, attention can be concentrated upon one of them, and objective appearance can be used with some certainty as a criterion of the character.

Tumblers were finally chosen as the subjects of the experiments for several reasons. Among these were the fact that Tumblers occur in a large number of well established varieties, not only of self-colored* birds, but of those with patterns as well. There are both "clean legged" and "muffed" varieties.† Furthermore, the Long-face Tumblers‡ are "good feeders," and can usually be depended upon to raise a good proportion of their young. Finally, they are smaller than some of the other breeds, and consequently consume less feed, which amounts in time to a considerable item. Since the offspring must be raised to maturity or at least until fully feathered, no returns could be expected from the sale of squabs, which would otherwise have been an argument for using a larger breed.

Sources of Stock.

The original stock used in the experiments consisted of a few pairs bought from pigeon breeders, and in one or two cases from dealers whose names were obtained from poultry journals. More experience at the beginning and a wider acquaintance with breeders would have led to a more careful selection of stock from reliable breeders and, in so far as possible, from those making a specialty of raising the particular variety desired. Most of the later stock has come from such sources, which usually assures that it has been bred pure for some time at least with members of the same variety. By some this lack of knowledge in certain cases of the past history and breeding of the stock used in the initiation of the experiments may be considered ground for criticism and for doubting the validity of the results

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*It seems hardly necessary to explain that "*self*-colored" means of the same color all over and without spots or markings. Blue and silver birds are, nevertheless, usually referred to as self-colored, although they have darker bands on the wings and tail.

†Feathers on the legs, called the "boot" in fowls, are known as the "muff" in pigeons.

‡Short-face Tumblers have a short beak and high, protruding forehead. While this condition is inherited, and is characteristic of the variety, it is often exaggerated by breeders, it is said, who dent in the fore part of the skull when the birds are young. Owing to their short beaks they have difficulty in feeding their young and it is a common practice to use foster parents to raise their squabs. Only birds of the long-faced variety have been used in these experiments.

obtained, as has been held with respect to certain of the work with fowls.* But while it is undoubtedly better to begin such studies in inheritance in as far as possible with stock which has been bred definitely to a particular type for a long period, and is therefore presumably "pure" for those characteristics which mark that type, the chief advantage is that it makes the task of the experimenter an easier one, in that the genetic analysis to be made is less complicated. There is no reason why a perfectly valid analysis of the heritable factors should not be made from a beginning with cross-bred stock, but in general the process would be a longer one in that the earlier results would be complicated, and consequently more confusing.

Furthermore, in attempting to obtain pure-bred pigeons one must depend entirely upon the word of the breeder. The purchase of prize winners in a particular color class, for example, at a show, would be no guaranty of obtaining pure bred birds, for it is well known that breeders often cross in with another color in order to effect improvement (as for example crossing red with yellows in order to improve the red, and conversely using red to improve yellow! See Goodwin, 1913), and consequently the prize winner may not be homozygous with respect even to the color of the class in which it is shown. As a result of the lack of any requirement respecting pedigree and breeding, it may result that a bird will be entered in an entirely different class from its parents.

As a matter of fact, the breeding experiments have shown that with one or two exceptions the pigeons procured for these experiments have been what they were represented. In one case, however, a pair of birds turned out to be obviously not what they had been represented; and although they probably contained no factors which were not present in other birds in the experiments, they and all their progeny were disposed of for the simple reason that the characters were too diverse and complicated for satisfactory analysis at that stage of the investigations. Finally, in pigeons, as in other animals, it is often only the rare individual which fulfills to a high degree the exacting requirements of the "Standard," and such an individual consequently has placed upon it a disproportionate valuation. In such cases, the other individuals, which do not approximate quite so closely to the "Standard," cannot, nevertheless, be considered as less purely bred. Accordingly, unless the experiments are concerned directly with the "fancy" points of the variety, these poorer birds often meet the requirements of the experiment fully as well as the prize winners. Thus, for example, if one were concerned only with the body color and markings of the Baldhead Tumbler, a specimen with a "bull" eye* might answer these requirements perfectly well, although this character might disqualify it in show competition. It might be argued that the possession of this defect is an indication of "impurity" of breeding, as it undoubtedly is in one sense. But this argument loses its force when we consider that the brother or sister of this bird may win a prize, although its breeding is exactly the same.

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*See for example Robinson. 1910.

Conduction of the Experiments: Acknowledgments.

Although the first birds were bought in December, 1906, the experimental work really was begun in 1907. During that season the experiments were under the direct supervision of the writer, although the actual care of the birds and the taking of the daily records were in charge of the chief assistant in the department, Mr. W. F. Kirkpatrick.† In this work he was ably assisted by Mr. D. W. Kolbe, whose practical experience in the handling and breeding of pigeons was of the greatest value at the inception of the investigation. In October, 1907, the writer removed to New Haven, Conn., but arrangements were made whereby the work could be continued without interruption. As all descriptions (with very few exceptions) were made by the writer, this necessitated frequent trips to Kingston; but it threw the routine of the experiments entirely upon Mr. Kirkpatrick, and it is safe to say that without his able and conscientious coöperation the work could not have been continued under the circumstances.* These arrangements were continued until July 1, 1910, when, through the generosity of Dr. H. J. Wheeler, then Director of the Rhode Island Station, a part of the stock was transferred to the University of Wisconsin, where the experiments have since been continued. In large part the present paper deals therefore only with results obtained up to July 1, 1910; but for the sake of completeness, in many instances records obtained since that time have been added, or at least statements made relative thereto.

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*Iris dark brown or hazel instead of pearl or white. (See Pl. II, Fig. 7.)

†Now professor of Poultry Husbandry at the Storrs (Connecticut) Agricultural College.

At Kingston the breeding was conducted in a small building originally constructed as a pigeon house, but which had not been used for that purpose in a long time. The pigeons previously kept in it had all died, apparently of some epidemic, within a day or two. Not only was the room it afforded soon inadequate, but in some other respects the conditions were far from ideal. The location was in the midst of the poultry plant, which was badly infested with rats, and infected with coccidiosis, and many birds were lost from both these causes,† especially young birds which were confined in one of the large covered poultry yards.

Material and Methods.

At the beginning of the work an attempt was made to secure representative pairs of the different self colors occurring in Tumblers, and it happened that the first ones secured were a pair of reds (♂ 1 A and ♀ 2 A) and two yellows (3 A and 4 A). It turned out however that both the yellows were females, so that it was a matter of chance that the first cross matings were between the reds and a pair of blacks (♂ 6 A and ♀ 7 A). As it happened, this chance occurrence gave direction to the major portion of the investigations for a considerable time, and the results of the red-black crosses form the most complete and detailed portion of the present report. It is interesting to note that if the initial crosses had happened to be between the reds and yellows we should probably have discovered the sex-linked relation of the intensity factor in pigeons two or three years earlier than we did.

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*Acknowledgment is due to the authorities of the Sheffield Scientific School of Yale University for permission to carry on this investigation in addition to my regular duties as instructor in that institution.

†With reference to coccidiosis in pigeons see Cole and Hadley, "Blackhead in Turkeys: A study in avian coccidiosis," Bull. 141, R. I. Agr. Expt. Sta., 1911.

Later additions to the stock consisted of whites, blues and silvers. These latter (i. e., the blues and silvers) could be found of good color only in the muffed varieties. No good duns were found in the regular Tumblers, and stock of this color was introduced in the Parlor or Inside Tumbler variety. More recently some of the distinctive patterns have been obtained and studied, and it has now become necessary even to extend the field of investigation to cover other breeds in order to test some of the points that have arisen.

The matings desired were made in the ordinary manner, that is, the male and female are placed in continuous cages with only a wire partition separating them, and are left so until they become acquainted and the female has reached that stage in her sexual cycle at which she will receive the attentions of the male. The two birds are then left together until well mated, after which, under ordinary conditions, their continued conjugal fidelity is fairly certain. The breeding pairs were not separated, but were kept together in a single room with attached outside fly. In the room were provided nesting places for at least twice as many nests as the number of pairs of mated birds. The cross-mating between different pairs cannot in this way be absolutely prevented without proper precautions, but with sufficient care and vigilance it may be rendered extremely unlikely. The danger of its sometimes taking place, however, may at first thought seem to introduce a serious element of experimental error, and only one who has had practical experience in raising pigeons can appreciate how small this danger really is if sufficient attention is given to it.

One of the chief precautions to avoid cross-mating is to have no odd birds of breeding age in the pen, but to be sure that all are mated pairs, and that they are going normally through their regular cycle of mating, nest building, laying, incubating and caring for the young.

If one bird of a pair becomes sick or disabled, both birds of the pair must be removed at once or trouble is likely to result. It is necessary also to be familiar with the individual birds and by daily observation to see that the proper birds are together. To facilitate these observations colored leg bands have been employed to a considerable extent, the same colors being put on the two birds of a pair—on the right leg of the male and the left leg of the female; and in other instances the birds have been marked by staining some of the feathers, and by other means. Furthermore, all nests are gone over daily in order to record new layings, hatching, etc., and to make certain that the rightful owners are sitting on the eggs or young. By these means cross-mating may, as has been said, be reduced to an almost negligible minimum, and a watchful caretaker, familiar with the habits and normal behavior of the birds, can usually detect at once any suspicious cases or cases of actual cross-mating.

In view of the above facts it is felt that all necessary reliance may be placed on the breeding records here recorded. On the other hand, the possibility of error is ever present when the pairs are not separated, and is not only unsatisfactory, but is a source of annoyance. Consequently it has recently become the practice, as fast as possible, to get all the pedigreed mating pairs into separate pens, and beginning with the present season (1914) it is planned to conduct all the breeding experiments in this way.

At the time of taking the daily records, all newly laid eggs are marked with their mating number and letter designating the individual.* For a considerable period one of the eggs was removed to an incubator shortly before they were due to hatch, and the squab hatching from it was marked with a thread around the leg before it was returned to the nest. In this way it was possible not only to keep track of the parentage, but to know also whether a squab came from the first or second egg laid.†

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*For an account of the method of record keeping employed see Cole (1909).

†The special results gained from this work will be reported upon in a subsequent paper.

The Colors of Pigeons.

The fancier commonly recognizes seven principal or "primary" colors in pigeons, self varieties of all of which exist. These are red, black, yellow, dun, blue, silver and white. Though commonly included among the "selfs," the blue and silver varieties are often referred to as "barred," since in the case of these shades the body is not uniformly colored as in the others, but there are bars (black in blues, and dun in silvers) across the secondaries and at the tip of the tail. A general account of these different colors and their relations in inheritance will first be presented, and this will be followed by a statement of the experimental results upon which it is based.*

Red.

Red may be called the fundamental color in pigeons as is probably the case in fowls and in most mammals. It appears to be potentially always present, and if we let the factor for its production be represented by the letter *R*, we may say that apparently the factor *R* is never lacking from the gametic formula of pigeons. Therefore in the absence of other modifying or inhibiting factors a pigeon will be red. This, at least, is the name given the color by the fancier, though in reality it is a rich brown or chestnut.† There is considerable variation in the shade of the red, it being in some cases rather bright, or "sorrel," and in others a dark "dunnish or brick red," or of a purplish cast, which we have usually referred to as vinaceous. This last is sometimes called "plum color" by the fancier. For present purposes, however, it will suffice simply to refer all these shades to the single category red, since in all probability the variations (such as are not due to age, fading and the like) are attributable to distinct modifying factors. In certain cases this is actually known to be the explanation, and it is believed that further investigation will resolve the others in the same manner. The color may be modified over the whole body, but more usually it is certain regions, such as the rump, lower belly or flanks that show a different shade.

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*A detailed study of the colors and pigments involved has been made in the Experimental Breeding Laboratory of the University of Wisconsin, by Dr. Orren Lloyd-Jones, and will soon be published.

†Very close to the "pecan brown" of Ridgway (1912).

Black.

Black is due to a single factor added to the red. It is definitely dominant* to red, as will be shown in the discussion of experimental results. In the blacks, again, there is much variation in shade, but the color desired by the fancier is a good deep, dead, black, or "coal black," as it is sometimes designated. The principal defects in black are: (1) "weakness" of the black, resulting in reddish tips, causing a reddish suffusion especially on the breast, and "mealiness," that is a mixture of red and black, especially evident in the inner vanes of the primaries; and (2) a tendency to bluish. This is especially apt to occur in certain regions, such as the rump and base of tail. We have good reason to believe that these modifications are due to definite heritable factors, but they have not as yet been clearly worked out and their discussion is accordingly reserved until a future time. It is to be expected that the same factors modify the black as are responsible for the differences in red, but it has proven a matter of some difficulty to correlate them in the two cases, and in some instances it seems quite certain that the factors act upon the black pigmentation only.

In the case of both red and black the color is not so deep in the first definitive, or juvenal, plumage as it becomes after the first molt. The juvenal feathers, moreover, in addition to carrying the yellowish nest-down at their tips for a considerable time, are often deficient in black pigment at the distal margin. This leaves the tip much lighter in color, resulting in a light lacing of greater or less width. It may be a mere trace of buff or reddish; at other times it is a broader definite band; or again it may shade insensibly into the black. The former condition gives the appearance of more or less definite lacing, while the latter imparts a general reddish or "coppery" suffusion to the region in which it occurs. The lacing is usually more marked on the head, neck and wing coverts, while the breast shows the reddish suffusion. As has been indicated, the reddish color at the tips of the juvenal feathers may vary greatly. In some cases it is light buffy, in others, dark chestnut red. It may appear even darker than the red of red birds, owing no doubt to its association with the black pigment of the black birds. This condition of red showing in the plumage of black birds is referred to by the fancier as "kitiness" (Staples-Browne, 1908, p. 75).

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*Or, strictly speaking, epistatic.

After the first molt, with the advent of the second plumage, the buffy tips are usually entirely lost, although in certain cases a reddish suffusion of the breast (sometimes not easily distinguishable from the iridescence of this region) is retained throughout life. In birds which retain the reddish color on the breast the black is usually weak in other parts as well, and red commonly shows especially in the inner vanes of the primaries.

Not all black birds show buffy edgings in the juvenal plumage, but there are usually some traces of the light tips. Their occurrence does not appear to depend upon the homozygosity of the factor *B* (black), but rather upon some factor or factors which determine the *strength* of the pigmentation. The term "strength" as here used is not to be confused with "intensity," to be discussed presently.

Indications of blue in the plumage, or even definite blue areas, occur on many black pigeons. The birds may be black in all parts, but show a bluish or leaden overcast, resembling in appearance somewhat the "bloom" on a ripe plum. The fancier calls this condition "plum" or more often refers to it as a "hard" black, in contrast to the "soft," deep velvety black which is desired. Black birds may have a blue rump, in which case the basal two-thirds of the tail also is commonly dark blue, bringing into contrast the darker terminal band at the extremity of the tail. Quite frequently in such birds the undercolor, that is the color of the basal parts of the feathers which are normally covered by other feathers, is "weak" as regards black pigmentation, and has more or less of a bluish appearance. The inner vanes of the secondaries also may be bluish.

It is hoped later to be able to give a more complete analysis of the factors which are concerned in producing a good uniform black plumage, but in the present paper all the conditions described above are classified as "black." The breeding behavior proves this to be legitimate, since a single factor is responsible for black pigmentation, whereas a number of factors are concerned in making a good black bird in the fancier's sense.

Yellow.

The presence of an intensifying factor is necessary for the production of red as described above. If this factor (*I*) is absent the color is much lighter in shade and is known as yellow. Like the other colors described, it varies considerably, but what the fancier would consider a good yellow is about intermediate between "capucine buff" and "apricot buff" of Ridgway. Aside from variation in the shade of the color, some birds being lighter yellow and others darker, a dusky appearance, especially on rump and tail, is not infrequent. This may be due to the same factor which produces the dusky or purplish color in the same regions in reds, but the correlation of the two characters has not as yet been established with certainty. In spite of the variations, however, there is no difficulty in distinguishing the categories red and yellow.

As has been pointed out in a note published elsewhere (Cole, 1912), the *I* factor is definitely sex-linked in its inheritance. The question of sex-linked characters in pigeons is however, to form the subject of another paper, to be published soon, and accordingly, in this contribution, the factor *I* will be treated as though it were an ordinary Mendelian factor, sex not being taken into account. Sex being left out of consideration, there should be, of course, no disturbance of the ordinary Mendelian ratios, it being only necessary to bear in mind that all intense females are heterozygous for the factor *I*.

Dun.

This is the dilute condition of black, thus bearing the same relation to black that yellow does to red. In other words, a dun bird is a black which lacks the intensity factor I, and in fact there seems to be no better description of it than to say that it is a less intense black.

Dun varies greatly in appearance, and in our breeding it has been less usual to get good uniformly-colored duns than any other color. Duns commonly show silver where blacks are bluish; in our duns, furthermore, we find a great tendency to the check marking, a condition which will be dealt with further on. As a rule, nevertheless, blacks and duns may be distinguished without difficulty, though in the case of young birds doubt may sometimes exist as to the category in which they should be placed. Usually, however, the doubt may be dispelled by close examination and comparison with other birds.

There apparently is no regular dun variety of Outdoor Tumblers, but it is a well recognized color of Parlor Tumblers, and our dun birds have largely come from this source. It is, however, of course an easy matter to breed duns by mating birds containing the B factor with others lacking I. Thus, by way of example, we may consider the mating of black and yellow. If the male is yellow ($bbii$) and the female black ($BBIi$, that is heterozygous for I on account of the factor being sex-linked) all of the resulting female offspring in F_1 will be dun, while the males will be black (see Cole, 1912, *Case II*). In the reverse cross, black male ($BBII$) with yellow female ($bbii$), the F_1 offspring will all be black, but a certain proportion of dun birds will appear in F_2.

Blue.

This is the color of the wild Rock Pigeon (*Columba livia* Linn.) which Darwin believed to be the source from which all our domestic pigeons have been derived. The so-called blue of pigeons corresponds to "blue" and maltese in such other animals as maltese cats, "blue" rabbits, the Blue Andalusian fowl, etc., and is in reality not a blue but a neutral shade or gray. It corresponds closely to Ridgway's "gull gray" (Ridgway, 1912, Pl. LIII). The optical effect is due to a different arrangement of the pigment in the barbules from that which obtains in blacks. In blues the pigment is aggregated into clumps, while in blacks it is spread rather uniformly throughout the barbule. The microscopic appearances have been fully worked out by Dr. Lloyd-Jones and will be published by him (cf. foot note, p. 320). As the clumped condition which obtains in the wild pigeon as well as in domestic blues is recessive to black, in which the pigment is extended or spread through the barbule, we have assumed that this extension is due to a *spreading* factor, which we have accordingly designated as the factor *S*.

It has been mentioned on a previous page that blues in one sense should not be classed as self-colored, since they always have black wing bars and the black terminal band on the tail. This is true, at any rate, of blues of the wild type, such as occur among Tumblers and Homers. There are breeds of pigeons in which the wing is blue without black bars, or in which the black bars are partially or wholly replaced by white. We have, however, made no investigation of these varieties; accordingly the present discussion is based on blue as it occurs in the wild Rock Pigeon. The presence of the black bands in blues might be accounted for by assuming that although *S* is absent from other parts it is never absent from the regions of the bands. But we are led into a logical difficulty here if we postulate that *S* is a factor which segregates in the germ cells, and which must accordingly either be present, and presumably fully active in each resulting zygote, or else must be absent entirely. This conflict with the presence-and-absence hypothesis may, of course, be avoided by turning the explanation about and simply saying that the bars are regions which are from some unknown cause physiologically of such a nature that the pigment there spreads through the barbules regardless of *S*, while in other portions of the plumage it is unable so to spread without the stimulus supplied by the spreading factor. The ease with which the presence-and-absence hypothesis may be supported by such sophistical arguments is its greatest weakness, and the principal reason for its common use is probably its convenience in expressing the relation of positive (dominant) and negative (recessive) characters.

If a blue bird is then of the composition of a black, but lacking S, we should naturally look for a similar condition in the red series, in which B is lacking. Theoretically such birds should be obtained in F_2 by crossing blue and red as follows:

$$\text{Blue } (RRBBss) \times \text{Red } (RRbbSS)$$

$$F_1 \qquad \text{Black } (RRBbSs)$$

$$F_2\ 9\ \text{Black}\left\{\begin{array}{l}1\ RRBBSS\\ 2\ RRBbSS\\ 2\ RRBBSs\\ 4\ RRBbSs\end{array}\right.\ 3\ \text{Blue}\left\{\begin{array}{l}1\ RRBBss\\ 2\ RRBbss\end{array}\right.\ 3\ \text{Red}\left\{\begin{array}{l}1\ RRbbSS\\ 2\ RRbbSs\end{array}\right.\ 1\ RRbbss$$

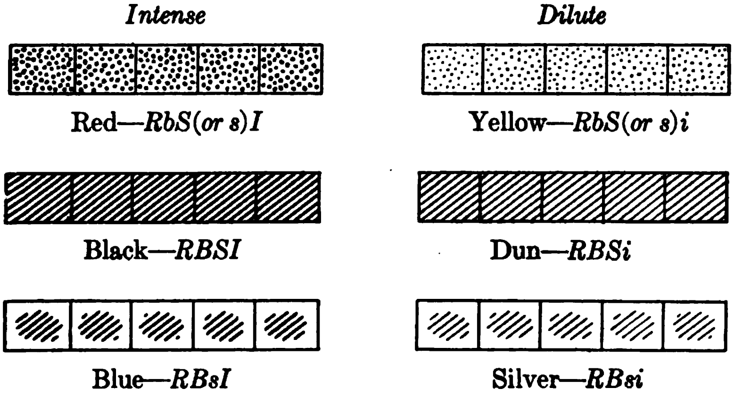
From this it will be seen that in F_2 one bird in sixteen should lack both B and S, and it was expected that this would be some form of red corresponding to blue. It was thought that possibly this condition might be represented by the color which occurs regularly among Homers, known as the Red-barred. In this variety the general body color is bluish, but the bars on the wings and the terminal band on the tail are red instead of black. In crosses made to test this point, however, no birds of this character were ever produced, and it seems probable now that the condition known as Red-barred in Homers, is really dependent upon another factor, acting on what would otherwise be an ordinary blue bird with black bars. This factor is sex-linked in its inheritance and will not be dealt with in the present paper. As a matter of fact then S appears to act only upon B, and not upon R. At any rate we have not as yet been able to identify any of the variations in red as correlated with the presence or absence of S.

Silver.

Silver is the dilute condition of blue, and accordingly bears the same relation to blue that dun bears to black. A silver is therefore of the composition of a black, but lacking both factors S and I ($RRBBssii$). In color it is very similar to blue, but lighter, or less intense, and the wing bars and tail band are dun instead of black.

It will thus be observed that the factor *I* affects all parts of the plumage, there being no exception in special regions.

The interrelation of the colors so far described may be illustrated succinctly by a diagram (Fig. 1). Each horizontal block of squares may be taken to represent a small portion of a barbule, the small squares defining the original cells of the barbule. No attempt is made to represent the actual color, shape or size of the granules, but only the relations of the different conditions. The intense series is represented in the left-hand column, the dilute series to the right.



Intense *Dilute*

Red—*RbS*(*or s*)*I* Yellow—*RbS*(*or s*)*i*

Black—*RBSI* Dun—*RBSi*

Blue—*RBsI* Silver—*RBsi*

FIG. 1. Diagram representing the colors red, yellow, black, dun, blue and silver.

White.

The white color of pigeons is not due to the presence of a white pigment, but to the reflection of light from the feather structures in which pigment is lacking. In this respect white pigeons agree with white birds and mammals generally. Good self whites are common, but the inheritance of white is not a simple matter, as will be seen.

The few investigators who have worked with pigeons are considerably at variance in their accounts of the manner of inheritance of white plumage. Thus Darwin (1900, "Animals and Plants under Domestication." First edition published in 1868) in his classical experiments in which the "reversionary blue" pigeons were obtained "crossed black Barbs (of two excellent strains) with purely-bred, snow-white Fantails. The Mongrels were generally quite black, with a few of the primary wing and tail feathers white: others were dark reddish-brown, and others snow-white" (*l. c.*, p. 205). The Black Barb is a self-black, having no white at all; the White Fantail is snow-white as Darwin states. This experiment has been repeated in recent times by Staples-Browne (1908) with similar results. He says (p. 69): "The F. 1 generation shows a dominance of black to white, and the further matings show that blue is also dominant to white. This dominance of the coloured to the non-coloured type is, however, imperfect, as the majority of birds produced from the mating of black or blue with white show some white feathers, chiefly on the rump."

Although it is concluded from the foregoing experiments that the colored condition is dominant to white it is to be noted that it cannot be considered by any means a complete dominance at any rate. Doncaster (1911) has investigated the matter further, and his results show even greater lack of dominance of self color. From a cross between a White Fantail ♂ and Red Tumbler ♀ (*l. c.*, p. 90) 10 "smoky black" or "deep smoky brown" young were obtained, all however, with more or less white markings. White Fantail ♂ × Black Fantail ♀ (p. 94) gave 13 young, all pied; 10 had more white than black, 3 more black than white. Two matings of the reverse cross were made, that is, Black Fantail ♂ × White Fantail ♀ (p. 95). The first gave 7 young resembling those of the preceding series, but with the black and white more evenly distributed. With a second white hen the same cock produced 12 offspring similar in general appearance, but with a greater range of variability and with a larger proportion showing a preponderance of white. As Doncaster had some doubt of the purity of the blacks used in these experiments he obtained two others of pure breeding and repeated the crosses (p. 97), but with essentially similar results.

Morgan (1911) has crossed a Blue Swallow cock on White Fantail hen and obtained seven offspring, all *pure white*, except that two of them has two or three slate-colored feathers near the outer edge of the wings. It should be noted that the Swallow is not a self-bird, but is colored on the top of the head, wings and muff, the other parts being white. Finally, Bond (1912 and 1913) has reported incidentally a cross between White Fantail and Black Tumbler and between Black Fantail and White Fantail. All his F_1 birds are splashes, and the further generations seem to accord very closely with the experimental results given further on in this bulletin.

The difficulty of interpreting all whites as recessive was recognized by Staples-Browne for in a cross of a White Fantail cock with a White Tumbler hen (1908, p. 95, ff.) he obtained six white offspring and three white with a few colored feathers. From two F_1 birds of the latter class bred together 10 F_2 progeny were obtained: 4 white; 4 white with a few colored feathers; and 2 "tricolor," that is red and white with some blue feathers. To account for these results, which would be incomprehensible if white were strictly recessive, Staples-Browne concludes that "the appearance of some coloured birds from these matings suggests the possibility that in the White Tumbler a dominant white factor, comparable with that known in fowls, may exist."

It is well known to the fancier that in general whites bred to selfs or to near-selfs produce for the most part "splashes," the term applied to white birds with a greater or less amount of colored feathers. These do not occur in the form of a definite pattern, although they are commonly more numerous in certain regions than others as will be described later. As a matter of fact the white pigeon is undoubtedly to be considered as the condition of extreme reduction of spotting, for it corresponds in all respects with those white mammals in which the production of pigment has become restricted to the eyes, as, for example, in white guinea-pigs with dark eyes. This interpretation is borne out by the fact that it is very difficult, if not impossible, to obtain white pigeons which will *always* throw perfectly white offspring without any colored, or "foul" feathers as the fancier calls them. I have been told by Tumbler breeders that in their experience there are no white Tumblers which do not occassionally produce offspring with some foul feathers. These may be limited to a very few, possibly only one or two small feathers, on the head, in which case they are usually found around the eyes. It is often only by special care that such feathers are not overlooked. If there are not too many foul feathers they are commonly removed by the fancier prior to showing, and such a bird, if sufficiently good in other respects, might even secure the first prize in the class for pure white birds.* Whether absolutely true-breeding white varieties occur in other breeds, I am unable to say; but I think there is no doubt that in the White Fantail and in the White African Owl there is a much greater tendency for the white to come absolutely true. Nevertheless, Staples-Browne (1908, p. 72) records that a bird he obtained from a well-known breeder of Fantails acquired a black feather at the molt following its purchase, and that at the various successive molts the replacing feather in this position was always black. No foul feathers appeared, however, in this bird's progeny. As Staples-Browne has reported (*l. c.*, p. 95), there appears to be a tendency for dark or "bull" eyes to accompany white plumage, and he states that if even "one or two coloured feathers are present in the plumage the correct eye-color is more easily produced." For this reason, in those breeds like the Tumbler, in which the Standard calls for a pearl eye, breeders often cross in with splashed birds in order to improve the eye-color.† This in itself may, of course, account for the difference in tendency to produce a few foul feathers, or even definitely splashed birds, in white varieties of the different breeds.

A true albino pigeon, that is a pure white bird with pink eyes,‡ has never been reported, so far as I am aware. Undoubted cases of albinos among wild birds are nevertheless on record. There is no reason to doubt that such a condition would behave in inheritance as albinism does in mammals, namely, as a simple Mendelian recessive to pigmentation.

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*A "legitimate" amount of "fitting" of this kind for the show is not considered unethical either with pigeons or fowls any more than washing the feathers of a bird in order to have it clean and in good condition, and is not classed as "faking." There seems to be no definite line between the two, however, and "faking" usually begins at the point where it becomes conspicuous enough to be detected by the judge.

†*Cf.* also Chapman (1911), p. 46.

‡This refers of course to the pupil and not to the iris; white birds with pink or red irises are frequent.

In view of the facts set forth above there seems no legitimate reason for considering white plumage, as it occurs in pigeons, as a recessive character, nor in distinguishing in this respect between the white of the Tumbler and Fantail. It seems better, as a provisional hypothesis, to regard white as due to an indefinite number of factors, the amount of white in the plumage depending upon the number of these factors which may be present. According to this interpretation each factor (W_1, W_2, W_3,——W_n) represents to a certain degree the inhibition of pigment production, and it may or may not be definitely located as to the place of its expression. It is not necessary to assume that these factors are all of equal value: some might represent very little white, others a considerable amount. Or indeed, they might even be qualitatively different; for example, some might produce the same amount of white whether present in duplex or simplex condition, while others might produce an intermediate amount of white when in the heterozygous condition. To be specific, W_1w_1 might produce as much effect as W_1W_1, that is to say W_1 is completely dominant. On the other hand, in the case of another of the "white" factors, say W_2, the heterozygous condition, W_2w_2 might produce only half as much white as would result from the homozygous presence of the factor, W_2W_2.

This explanation is advanced only as a convenient formula, in line with the multiple-factor hypothesis in general. It would be very difficult of proof, especially in pigeons, where it is impossible to obtain anything like adequate numbers of offspring, and consequently very little has been done towards an analysis of the factors. A suggestion along much the same line was made by Doncaster (1911, p. 97) to account for the perplexing results obtained by him, but it is evident that such simple formulæ as he proposed will not explain the complicated conditions which exist.

The Markings of Pigeons.

Splash.

As has been stated in the foregoing section, Splashed birds are those in which there is an intermingling of white and colored feathers, but without definite pattern. The condition was explained on the assumption of an indefinite number of determiners for white. When the bird is predominatingly colored, and the white occurs in fairly distinct spots, it is sometimes spoken of as "mottled" with white; but as there is a variety of Tumbler with a fairly distinct color pattern which is known as a Mottle, confusion is apt to arise in the use of this term. Moreover, unless the white spots form a definite pattern, there seems no good reason for taking such birds out of the series of Splashes.

In Splashes both red and black, or partially red and partially black, feathers may be found on the same bird; and these may be distributed without any apparent order. In certain cases, feathers of a particular color may regularly occur in a definite region, as blue feathers with black terminal bands in the tail. Such a bird is to be explained as one which has the requisite factors for blue tail, but can only show the blue in such parts as the *W*-factors are absent, and hence expression of the color is not inhibited. As regards the separate occurrence of black and red in the contour feathers, there are probably factors which act on black alone in a way similar to that in which the *W*-factors are assumed to affect all pigmentation. In other words, there are restriction factors which act specifically on the factor *B*. One such factor has in fact been determined and its inheritance, which is sex-linked in behavior, worked out in some detail. It will receive consideration, with other sex-linked characters, in a future paper.

It should be noted that, although feathers in the categories red, black, and blue may occur on the same splashed bird, the same is not true of intense and dilute. In other words *I*, when present, affects all parts of the plumage, as well as beak and claws, and all pigmented feathers will be intense. If the intensity factor is absent all pigment will be dilute. This fact is a great convenience in determining the presence or absence of *I* in birds which are practically white, for the presence of a single pigmented feather is sufficient to settle the point. In some cases one or two minute feathers above the eye, though so small that it has been necessary to examine them with a hand lens, have made it possible to tell whether the bird should be classed as intense or dilute.

Should the factor *B* be lacking, the splashed bird will have only red or yellow colored feathers, depending on whether or not it carries the intensity factor. The absence of feathers containing black pigment is not in itself, however sufficient evidence for assuming that *B* is entirely absent, for it may be that its expression is inhibited in those parts where it would show except for the *W*-factors. This readily accounts for the fact that two Splashes showing only red and white may produce offspring with black feathers. The condition is therefore directly comparable to that of tricolor Guinea-pigs.

Special Patterns.

By the term *pattern* as here used, is meant a combination of white and colored areas to form a more or less definite marking. This restriction of the word to combinations involving white is arbitrary and is made only for present convenience, since differences in color of pigmented parts (e. g., blue rump, blue tail on black bird, check, etc.,) are treated separately. As a matter of fact most of the distinctive patterns are dependent on the distribution of white areas. In Tumblers several well-recognized *pattern* varieties are found: Mottles, Rosewings, Beards, Baldheads, Whitesides, Saddles and Badges may be mentioned. Each of these patterns may occur, theoretically, in any of the colors which have been described for pigeons, though as a matter of fact some of them are not regularly found owing to their not being popular among fanciers.

According to Standard requirements the various patterns should be very definite in their limitations, but in actual breeding practice they are far from being so. In birds of good breeding the white and colored areas will be reproduced in a general way, but there is great variation in their extent, the boundaries may be irregular, white feathers may invade the colored areas, or conversely colored feathers, may occur on parts that should be pure white. Consequently, it is only the occasional bird that conforms closely to the ideal set up in the Standard. The same difficulty is experienced, of course, by breeders of live stock and of domesticated animals in general. The variation which occurs in the marking of the Dutch rabbit, in spite of all selection, may serve as an example.

It is not the purpose of this paper to discuss whether the fluctuations of this character are due to variation in the heritable factors or genes concerned themselves, as maintained by Castle (1914), or whether they should be accounted for by postulating a larger number of invariable factors (East, 1913). In our present state of knowledge of the subject either theory might be used to explain the known facts. It does seem certain, however, that the main features of the pattern are dependent upon definite factors, whether immutable or not, and that these factors are of the same general nature as the *W*-factors already postulated in that they are inhibitors of pigment formation. They differ from the *W*-factors only in the matter of more definite localization of expression. It is not improbable that there are intergrades between the two types, and there is no doubt both kinds are often present together in splashed birds.

That more than one pattern-factor is concerned in most of the patterns that have been mentioned above is easily discernible from an inspection of the characteristics of the varieties themselves. Thus we find that the Rosewing is simply the Mottle lacking the markings on the back, but retaining those on the wings; the Badge has practically the same markings on the head as the Saddle, but differs on the wings and body in that only the primaries should be white, while in the Saddle the whole wing and belly are white; and other similar examples might easily be adduced. Since, however, the experimental study of pattern inheritance is not to be included in the present bulletin, the above may stand for a general account.

Check.*

There is no regular variety of checkered Tumbler, and the marking which crops out frequently in crosses, is considered a defect. As a regular varietal marking it is probably best developed in the Homer. In general appearance it consists of light triangular markings on the wings, but it exists in varying degree, and is by no means a simple condition. There appear to be two principal types of check, though they may grade rather insensibly into each other. The first type, which we have called the *central shaft type,* is due to a light V-shaped marking at the distal end of the feather, the narrow end of the V extending up the central shaft of the feather. The other we have designated the *inner-vane type* of check, since in this case a greater or less portion of the inner vane of the feather is lighter in color than the outer vane. A specimen largely of this type is illustrated in Fig. 1, Pl. I. As the feathers naturally lie on the bird only the outer vane and a portion of the inner vane at the tip are exposed; as a consequence the second type may produce essentially the same appearance of check as the first. In black birds the lighter portion of the feather in either type is blue or bluish, while in dun birds it is silvery. It is doubtful whether the factor or factors which represent check can gain expression unless B is present in the gametic formula of the bird. While Red and Yellow Tumblers may not always be perfectly uniform in coloration of the wing coverts, still they do not show a definite check.†

Bonhote and Smalley (1911), who used birds in which checking is a characteristic marking (Dragoons and Homers), found check dominant to self-color. Bateson (1909, p. 43) had previously made the same statement on the authority of Staples-Browne (see Bonhote and Smalley, 1911, p. 607, footnote).

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*English spelling, (*cheque*.)

†It may be recalled (cf. p. 326) that B is probably present in certain Red Homers.

Grizzling, Mealiness, Frosting, Etc.

The inheritance of the characters mentioned in this section is not considered in this report, but mention of them is included for the sake of completeness. Like checking they are markings of the individual feather. They may be confined to comparatively few feathers in the plumage, or may be extensive, in which case they modify markedly the appearance of the bird.

Grizzling. A grizzled feather, according to Bonhote and Smalley (1911, p. 602) is "one in which the barbs are partially white and partially coloured." In common usage, however, the term is employed somewhat more loosely to designate any condition which owing to a rather intimate mixture of black and white or blue and white has a "grizzled" appearance.

Mealiness. In a mealy feather the white is wholly or partially replaced by red. A typical appearance is that of a sprinkling of black and red dots.*

Bonhote and Smalley (1911, p. 619) present the following conclusions with respect to the inheritance of Grizzle and Mealy:†

"Chequering is dominant to its absence (i. e. a Self-colour).

"Grizzling is dominant to its absence (i. e. a Self-colour).

"Grizzling is dominant to Chequering; the impure dominants may however sometimes be easily distinguished.

"A Mealy is a Grizzled bird with the White wholly or partially replaced by Red.

"Red in a Mealy is apparently dominant to White, and hence a Mealy is dominant to a Grizzle.

"White and Grizzling when they have met combine together and have a common inheritance.

"Red combines with Grizzling in the same way as does White."

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*In what has been said of black, red and blue, it must be understood, of course, that the same applies to the dilute condition of these colors.

†The "Self-colour" referred to by Bonhote and Smalley is the condition lacking our factor *S*; that is, they were blue and silver barred birds. It is undoubtedly for this reason that he found checking behaving as a dominant.

Frosting. I am not sure that this is a term regularly used by the fancier, but it is one we have employed to describe a condition which in general appearance is rather like grizzling. It is due to the presence of white distal margins on the contour feathers. It is a condition much like kitiness, but with the red tips replaced by white, which of course gives a very different general effect. Frosting occurs commonly to some extent as an intermediate condition on Mottles and on cross-breds between Mottles and self-colored birds. It is intermediate between the wholly white feather which makes the characteristic mottle marking, and the wholly colored feather of the plumage in general.

Various other markings of individual feathers are to be found in pigeons, but they are mostly more oı less indefinite and difficult to classify. In birds with good wing bars, the bars are formed by dark markings on the secondaries and on the greater wing coverts. But although these markings give the appearance of continuous bars when the feathers are in place, if the feathers are examined individually it will be found that the dark marking is in reality confined to the outer vane of the feather, and only rarely extends to the inner vane. Feathers with more or less distinct indications of a dark bar may sometimes be found in pigeons, but I have never seen anything that could be compared with barring as found in fowls.

Splashing or blotching of individual feathers with different color or with white appears to occur more commonly in some breeds of pigeons than in others. The usual color found in Almond Tumblers seems to be due to the peculiar markings of the individual feathers, but I have never had opportunity to examine carefully the plumage of one of these birds.

Iridescence.

In the foregoing discussion the purplish and greenish iridescent colors of the neck and breast of pigeons have not been taken into account. As is well known this effect is due to the structure of the feathers, and not to pigment, although the underlying pigment has a contributory influence in the general effect. There is no doubt that in white birds the structure is the same, but there is little or no iridescence. It occurs in full strength, however, in colored feathers which happen to occur in this region on splashed birds, even though the bird is practically all white with only a few pigmented feathers. The iridescence is relatively slight in the juvenal plumage, and only comes out in full brilliancy after the first molt. In old birds it often extends well down the back, including even the rump and upper tail coverts. If heritable variations in iridescence in the domestic pigeon occur, they have not been recorded nor studied, so far as I am aware.

Reversion.

Darwin's principal interest in domestic pigeons was their great diversity in form and feather, in spite of which, however, he was able to find abundant evidence of close relationship. As a result of his extensive observations, collection of facts, and his breeding experiments, he becomes convinced that domestic pigeons are monophyletic in origin—that all the diverse forms have had their origin from a single wild species, the Wild Rock Pigeon (*Columba livia* Linn.).* One of the strongest arguments advanced by him was the evident tendency in domestic stock to revert more or less completely to the blue color of the Rock Pigeon. He cites (Darwin, 1900, pp. 200–208) many instances in which blue has appeared, especially in wings and tail, in crosses of birds showing no trace of blue possibly for several generations back, and then gives the details of his own experiments which can probably best be summarized in diagramatic form.

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*According to Beeck (1908, p. 25), the correct name for the Wild Rock Pigeon is *Columba livida* Briss.

It should be noted furthermore, that all investigators do not agree with Darwin that the domestic pigeons are monophyletic in origin; see for example Ghigi (1908).

Barb ♂ × *Spot* ♀
(Self black) ↓ (White with red spot on forehead and red tail)
F$_1$ *Barb-Spot*
(Black or brown with some white splashes)
↓
"*Mongrel Barb-Spot*" ♂
(Generation not stated)

Barb × *Fantail*
(Self black) (Self white)
↓
F$_1$ *Barb-Fantail*
(Black, with some white flights and tail feathers)
↓
"*Mongrel Barb-Fantail*" ♀
(Generation not stated)

"*Mongrel Barb-Spot*" ♂ × "*Mongrel Barb-Fantail*" ♀
↓
Reversionary Blue
(One bird; head tinted with red)

Darwin's blue bird was essentially like the Rock Pigeon in color. It is probable that the tint of red on the head was the "kitiness" so often observed in young birds and which usually disappears with molt, rather than a condition depending upon the red forehead of the Spot ancestor. Figure 2, Plate I, is a Wild Rock Pigeon; Figure 3 on the same plate shows an ordinary blue domestic pigeon, corresponding to what Darwin termed the reversionary form. The fact that its rump is much darker than that of the wild bird is noticeable in the photograph. This condition is characteristic of *C. intermedia* of India, which apparently differs from true *C. livia* only in this respect.

Staples-Browne (1908) has repeated Darwin's experiment as nearly as he could. Not having a Spot to use, however, he bred together the F$_1$ birds obtained from the crossing of Black Barb × White Fantail. As his results are given in greater detail it will be better to give our consideration largely to them. They may be tabulated as follows:

Barb × *Fantail*
(Black) ↓ (White)
F$_1$—*Black* (with white feathers)
↓
F$_2$—*Black* (self)
Black (with white feathers)
"*Blue*" (self)
"*Blue*" (with white feathers)
Red (with white feathers)
White (with colored feathers)
White (self)

It should be noted particularly that the so-called "reversionary blues" obtained by Staples-Browne were not like the blue of the Rock Pigeon or of the bird mentioned above in Darwin's experiment. They were, on the contrary, what are classified in the present paper as black birds with blue tails (*BSt*). A specimen of this nature is shown in Fig. 4, Plate I.

In reading over Darwin's account in the light of our present knowledge it is interesting to see how closely the facts presented by him coincide with the factorial hypothesis and how narrowly he missed such an explanation. Although Staples-Browne's paper was written from the Mendelian point of view, and he handled specifically certain of the color characters, such as black, blue and white, he offered no definite factorial explanation of these cases of "reversion" further than to suggest that "some factor of the blue did come from the Fantail" (*l. c.*, p. 68).* Punnett (1907, p. 55) in the preceding year had suggested that Darwin's result was to be explained like that of the recurrence of single comb in the second generation in fowls, after a cross involving rose and pea comb. He suggests that "blue underlies the blackness of the barb, but owing to the dominance of black it cannot become manifest except in zygotes which do not contain the latter. And this can only happen in the second generation." In a later edition of his book Punnett (1911, pp. 65–67) discusses Staples-Browne's results and amplifies his former explanation. The assumption is made that two factors are concerned—*C*, a factor for color, which produces blue when present alone; and *B*, which modifies *C* to produce black. In the absence of *C* the bird is white whether *B* is present or not. With these premises the formula of the Black Barb would be *CCBB*, while the White Fantail would be represented by *ccbb*. The first cross-bred generation would of course be black (*CcBb*) and in F_2 there should be blacks, blues and whites in the ratio of 9:3:4. When white is treated in this way as a definite factor, it is difficult to account for the large proportion of splashed birds; and furthermore

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*It is unfortunate in a way that Staples-Browne focussed his attention so much on *white*, trying to study it as a simple character. Had he disregarded white for the time, it seems certain he would have made out more clearly the relations of the other characters involved.

Punnett has left out of consideration the reds. Neither do Staples-Browne's results approach closely the 9:3:4 ratio as is assumed by Punnett.

It seems perfectly feasible, by means of the factors which have already been suggested in this paper to give a representation which shall explain the essential results of Staples-Browne's experiments. The second generation offspring obtained in the experiment described may be summarized as shown in Table I.

TABLE I.—*Results obtained in F_2 by Staples-Browne from cross of Black Barb with White Fantail.*

						Splashed		
CATEGORIES OBTAINED	Black (B)	Red (b)	Black tail (T)	Blue tail (t)	Pigmented (self)	Little white	Much white	White (self)
5 Black (self)	5	..	5	..	5	..	..	..
10 Black (w. f.)*	10	..	10	..	..	10	..	..
2 "Blue" (self)	2	..	..	2	2	..	..	..
2 "Blue" (w. f.)	2	..	..	2	..	2	..	..
5 Red (w. f.)	..	5	?	?	..	2	..	..
4 White (c. f., 2 w. black, 2 w. red)*	2	2	?	?	..	..	4	..
6 White (self)	?	?	?	?	..	..	..	6
Totals	21	7	15	4	7	14	4	6
Expectation	*21*	*7*	*14.25*	*4.75*	?	?	?	?

*The abbreviation "w. f." means "with white feathers;" "c. f." means "with colored feathers." We should refer to all these as splashed birds, some with *little white* and some with *much white.*

It is here assumed that the factorial composition of the two grand parental breeds was—

Black Barb — $BBSSTTw_nw_n$;
White Fantail — $bbSSttW_nW_n$.

Examining these formulæ we see that the Barb carries black pigment (B) which is spread (S) in the barbules producing a black appearance instead of blue; this applies also to the tail (T); and the bird is a *self* black because there are no W factors present. The Fantail has an undetermined number of factors which make it white

(W_n), otherwise it would be red. The effect of S and T we have not identified in red birds (see p. 326), but it is assumed that S is present because no blues of the *C. livia* type were obtained in the F_2, and that T is absent because blue-tailed birds were obtained. The birds therefore differ with respect to factors representing three conditions, (B) black, (T) tail color, and (W) white. For present purposes the last will be discussed very briefly as we have too few data to determine how many W factors may be concerned. In general, it may be said, however, that such results as were obtained coincide with the multiple-factor hypothesis. The unfortunate part about white is that, where there is much of it present, because of its inhibition of other factors, it is impossible to tell from the appearance of an animal what other factors may be present. This is the case of the 6 self whites in the experiment. The presence of some colored feathers in the 4 other birds which were mostly white makes it possible to assign the two of them in which the feathers were black definitely to the class carrying B. The other two had a few red feathers, and the presumption is that they lacked B; this cannot however be positively asserted, since black might have appeared elsewhere in the plumage had it not been inhibited. For our purposes, nevertheless, they have been considered as b birds.

The F_1 from the above cross would have the composition $BbSSTtW_nw_n$, and consequently would be a black bird like the Barb parent except that it would be more or less splashed with white. This is what was obtained. But leaving the white out of consideration, and turning our attention now to B and T, we have an ordinary case of dihybridism. Considering the factors separately, a 3:1 ratio is to be expected in F_2 in the case of each. Reference to the table will show that this, as it happened, was obtained exactly in the case of B (21 black to 7 red), and closely approximated in the other case (15 black-tailed to 4 blue-tailed; expectation 14.25:4.75).

The dihybrid expectations and the results actually obtained by Staples-Browne may be shown in the following tabular form:

Expected ratio	9 *BT* (Self black)	:	3 *Bt* (Black with blue tail)	:	3 *bT* : 1 *bt* (=4 Red)
Numbers obtained	15 "	:	4 "	:	5 "
Numbers expected	13.5 "	:	4.5 "	:	6 "

In this calculation the 6 white birds and the 4 "white with colored feathers" have to be left out of account owing to the fact that we cannot determine in which of the categories they would fall. This leaves only 24 birds to be classified, and considering the small number it will be seen that they approach very closely the expected ratio of 9 self black: 3 black with blue tail : 4 red.

The above discussion of "reversion" in pigeons has been presented in considerable detail on account of the rather classical position of these examples in relation to the subject of reversion in general. It seems to demonstrate beyond doubt that the frequent reappearance of blue color in domestic pigeons falls in that common class of reversions which are due to factorial recombinations. Further evidence concerning the factors involved will be brought out in the discussion of experimental results.

Experimental Results.

The earlier part of this report comprises a synopsis of the principal color characteristics of pigeons and their inheritance. In the present section it is proposed to present the experimental evidence in substantiation of the conclusions there stated. No attempt will be made to present the details of all the experimental work, but selection will be made of such material as seems pertinent to the topic of discussion and an attempt will be made to arrange this in a manner that will show its bearings upon the point most clearly.

The B-Factor.

Black-Red Experiment. The dominance of black to red in the first generation, and the reappearance of red offspring in the second filial generation were pointed out in 1908, in a preliminary report on the present experiments (Cole, 1908, p. 301). It was apparent even at that time that the proportion of recessive reds was greater than the expected ratio of 1 in 4. These same matings have now been carried along for several years, so that what amounts to a very considerable number of offspring for such slowly reproducing animals as pigeons has been produced. Another preliminary statement was made (Cole, 1911) at a time when 71 F_2 offspring had been obtained, the numbers at that time standing 45 black to 26 red. It is now proposed to present below a complete account of this experiment and a summation of a considerable number of other matings involving the $\dot{B}$-factor. The experiments with self-black and red (intense) birds will be considered first.

This experiment was begun with a pair of reds (♂ 1 A and ♀ 2 A) and a pair of good self blacks (♂ 6 A and ♀ 7 A). These birds were acquired by purchase, and nothing is known of their breeding. The red ♂ (1 A) though of good color had a few white feathers in each wing-bow, indicating very likely, birds of the rose-wing pattern in his ancestry; and at one molt the female also showed a single white feather in the same situation, so that she was probably of the same breeding as the male and may have been related to him. Since "pattern" is entirely independent of "pigmentation," in its inheritance this tendency toward the rose-wing pattern in the reds may be disregarded in the present discussion.

Before the reds and blacks were crossed young were reared from them mated as they were received, and they have subsequently been mated together at other times. In all 16 young have been reared from each pair in this way, and in all cases the original birds have bred true to color, that is to say, the 16 young of the reds have all been red (in some cases showing the same tendency to "rose-wing" as the parents), and the 16 offspring from the blacks have all been black. Practically all of these showed more or less conspicuous buffy tips on the juvenal feathers.

From reciprocal cross-matings of these two pairs 27 offspring were obtained, all black—13 from ♂ 1 A (red) × ♀ 7 A (black) and 14 from ♂ 6 A (black) × ♀ 2 A (red). In all these young the buffy tips to the juvenal plumage were usually pronounced, and in some cases (especially in the cross of black ♂ with red ♀) there was much "kitiness," the breast sometimes being suffused with red and the inner vanes of the primaries decidedly "rusty." In most cases this red disappeared at the first molt; but some birds still show indications of it on the breast even after attaining adult plumage. From the red ♀ were obtained also some young with blue rumps and with more or less tendency to blue in other parts; but as has been stated, there is good reason for assuming that these variations are due to supplemental factors, and they can therefore be disregarded at present and the birds be classified on the basis of the presence or absence of black pigmentation.

The results of this experiment, including the F_2 generation, are summarized in Table II.

TABLE II.—*Results of Black-Red Experiment.*

PARENTS		OFFSPRING		RATIO—BLACK : RED	
♂	♀	Black	Red	Obtained	Expected
1 A (red)	2 A (red)	......	16	0 : 1	0 : 1
6 A (black)	7 A (black)	16	......	1 : 0	1 : 0
1 A (red)	7 A (black)	13	......	1 : 0	1 : 0
6 A (black)	2 A (red)	14	......	1 : 0	1 : 0
Total		27	0	1 : 0	1 : 0
28 B (F_1–black)	71 A (F_1–black)	18	8	2.25 : 1	3 : 1
45 A (F_1–black)	56 B (F_1–black)	3	3	1.00 : 1	3 : 1
45 B (F_1–black)	56 A (F_1–black)	27	14	1.93 : 1	3 : 1
46 B (F_1–black)	46 A (F_1–black)	8	7	1.14 : 1	3 : 1
Total		56	32	1.75 : 1	3 : 1

The first two rows show the results from mating red to red and black to black. The two rows next below show the production of 27 F_1 offspring, all black, from mating red to black and black to red. In the lowest division of the table are four matings of F_1 birds, bred *inter se*. Of these birds, 28 B, 46 A and 46 B are from mating 1 A (red) × 7 A (black); 71 A, 45 A, 45 B, 56 A and 56 B are from 6 A (black) × 2 A (red).

It will be observed that in each of these four matings taken individually, and consequently also in the total numbers for all four, the proportion of red offspring is considerably greater than would be expected in an ordinary Mendelian monohybrid cross, in the totals the ratio of black to red being only 1.75 : 1.

Table III shows the results of matings of F_2 birds together, also some matings of birds of one generation with those of another; but all are descended from the two original crosses indicated in the middle portion of Table II

TABLE III.—*Further Results from Black-Red Crosses.*

PARENTS		OFFSPRING		RATIO—BLACK : RED	
♂	♀	Black	Red	Obtained	Expected
307 A (F_2–black)	303 A (F_2–black)	2	1	2.0 : 1	3 : 1
307 A (F_2–black)	221 B (F_2–black)	8	3	2.67 : 1	3 : 1
448 A (F_2–black)	432 B (F_2–black)	11	2	5.5 : 1	3 : 1
194 B (F_1–black)	481 B (F_2–black)	1	..	1.0 : 0	3 : 1
194 B (F_1–black)	559 A (F_2–black)	5	3	1.67 : 1	3 : 1
	Total...............	27	9	3.0 : 1	3 : 1
145 B (F_2–red)	221 B (F_2–black)	2	......	1.0 : 0	1 : 1
307 A (F_2–black)	429 Y (F_2–red)	4	4	1.0 : 1	1 : 1
448 A (F_2–black)	936 A (F_2–red)	0	1	0.0 : 1	1 : 1
483 Y (F_2–black)	481 A (F_2–red)	10	12	0.83 : 1	1 : 1
538 A (F_2–red)	644 A (F_3–black)	2	5	0.5 : 1	1 : 1
545 X (F_2–red)	221 B (F_2–black)	2	4	0.5 : 1	1 : 1
886 A (F_2–black)	559 B (F_2–red)	2	2	1.0 : 1	1 : 1
	Total...............	22	28	0.79 : 1	1 : 1
145 B (F_2–red)	432 A (F_2–red)	(1)*	2	0.0 : 1	0 : 1
409 B (F_2–red)	429 Y (F_2–red)	......	3	0.0 : 1	0 : 1
545 X (F_2–red)	429 Y (F_2–red)	......	2	0.0 : 1	0 : 1
	Total...............	(1)*	7	0.0 : 1	0 : 1
493 B (F_2–black)	454 B (F_2–black)	3	......	1.0 : 0	1 : 0
134 B (F_1–black)	454 B (F_2–black)	3	......	1.0 : 0	1 : 0
	Total...............	6	0	1.0 : 0	1 : 0

*Undoubtedly an incorrect record. See text.

In the first horizontal section of this table are shown matings of heterozygous black birds, all belonging to the F_2 generation except 194 B, which is an F_1. The expectation of 3 to 1 happens here to be exactly realized, there being 27 black and 9 red offspring. The second section of the table shows matings of heterozygous blacks to reds, giving an expectation of equal numbers of black and red progeny. Here again most of the birds are F_2's, some of the blacks being the same that were listed in the section above. The results show a total of 22 blacks to 28 reds, which taken by itself would not be a significant departure from the expected ratios where such small numbers are concerned. The third section of the table records matings of "extracted" F_2 reds together. The results show all red offspring except for one bird in mating ♂ 145 B × ♀ 432 A, which is recorded as black. The breeding history of 145 B, however, shows that although he assisted in incubation and the rearing of young he early became impotent as a breeder. Many of the eggs were abandoned or were sterile, and when he was later isolated with a female no fertile eggs were produced. All squabs raised after the first two showed definitely by their characters that 145 B could not be the father, and it therefore seems justifiable to attribute the occurrence of this black squab where red would be expected to an illegitimate union of ♀ 432 A with a black male. Abundant matings of red with red, many of which are controlled beyond any possibility of doubt, demonstrate that red is recessive to black, and black cannot be produced from such matings, in which it is absent from both parents. It should be recalled in this connection, however, that there is a type of red bird which carries black, and from such reds black offspring may result. This is due to an additional factor which is an inihibtor of black and is sex-linked in its inheritance. It suffices at the present time to state that it is definitely known that this factor was not present in ♂ 145 B, nor in fact in any of the birds in the experiment under consideration.

Finally, in the fourth section of Table III are shown two matings of ♀ 454 B, the only F_2 bird of this experiment which has been satisfactorily proven to be homozygous for *B*. Of the two matings shown, the first proves nothing since it is not known whether ♀ 493 B is a *BB* or a *Bb* bird. The F_1 male, 134 B, is of course *Bb;* but only 3 offspring were produced, so that this mating again has little meaning. But in addition to the matings shown here, ♀ 454 B was also mated to an unrelated red (912A) heterozygous for *I*, resulting in 7 black and 1 dun offspring, the expectation being in the ratio of 3 black : 1 dun. This seems sufficient to establish her homozygosity for *B* beyond reasonable doubt.

Discussion of Ratios Obtained. The ratios obtained in this cross show some features of interest. Mention has already been made of the fact that even early in the experiment there was evident a tendency to an over-production of extracted reds in the F_2 generation. The numbers are relatively so small that this might not be thought to have significance if it were not for the fact that it occurred so consistently. There appears to be a tendency throughout for an approach to a 2 : 1 instead of a 3 : 1 ratio. The final ratio obtained for straight F_2 birds, as shown in the lower section of Table II, was 56 blacks to 32 reds, or only 1.75 : 1. In each of the four individual matings the reds were in excess of expectation. In the matings of heterozygous blacks of the F_2 generation (in one case F_1 with F_2) shown in Table III, where also the expectation is 3 : 1, it happens that this ratio is exactly realized by 27 blacks to 9 reds. This result is due to the large proportion of blacks in a single mating (11 blacks to 2 reds from ♂ 448 A × ♀ 432 B), the only case in the whole series of matings in which blacks were obtained in excess of expectation. Combining the 56 blacks and 32 reds of Table II with the 27 blacks and 9 reds of Table III gives us a total of 83 blacks to 41 reds, a ratio of almost exactly 2 : 1. While it may be contended that the total numbers are not large, still it must be conceded that the departure from a 3 : 1 ratio is so great as to be significant. On the basis of a 3 : 1 ratio the expected number of blacks is 93, the observed deviation therefore being—10. The probable error of the expectation for any given number of individuals may be calculated by the formula P. E. = $0.67449 \sqrt{npq}$, first applied to Mendelian ratios by Weldon (1902), where n is the number of individuals, and p and q the proportions of those expected in the black and red classes respectively.* For 124 individuals P. E. = ± 3.255. Dividing the observed deviation by this number gives 3.072, which, according to the table recently published by Pearl and Miner (1914), means that the probability of a deviation as great as 10 occurring with this number of individuals is only 4.3 in 100, or in other words, the odds are 22.26 to 1 against a deviation as great as this being due solely to chance.

Making the same calculations now on the basis of a 2 : 1 ratio, P. E. = ± 5.26; but the observed deviation from a 2 : 1 ratio is only 0.33, and this number divided by the probable error = 0.093. This number is so small that it is evident the observed deviation is well within the deviation which might be expected as a result of chance, and consequently the numbers obtained might well indicate a true 2 : 1 ratio.

Considering now the matings of heterozygous blacks, of the F_2 and F_3 generations with reds (second section of Table III), in which case the expectation is an equal number of black and red offspring, we find a total of 22 black to 28 reds, which is a ratio of 0.79 : 1 and again shows a deficiency of blacks. These numbers again taken by themselves are too small to have much meaning, but the fact that they coincide in direction with the others lends weight to the conclusions that there is in this experiment a definite tendency to an over-production of red offspring.

Two to one ratios have been observed in a number of cases, which fall into two classes. In the first class are the yellow mice, in which it seems quite probable that, as suggested by Castle and Little (1910), unions of yellow-carrying gametes with yellow-carrying gametes fail to develop, leaving two heterozygous yellows to one recessive. In the other class of cases it is the recessive which is non-viable (namely from etiolation, in plants), leaving a ratio of one homozygous dominant to two heterozygotes. The original example of the green and "aurea" forms of Antirrhinum described by Baur (1907) will serve for illustration. In the superficial respect that the result consists of two dominants to one recessive, black and red in pigeons corresponds more nearly to the mice; but as we shall see there is a fundamental difference between them.

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*Other formulæ have been developed for polyhybrid ratios, but for the monohybrid ratio the ordinary formula is suitable (Harris, 1912).

Modifications of the 3 : 1 or 1 : 2 : 1 ratio in F_2, in the case of simple allelomorphic characters, might be explained in several ways. They might be attributed (1) to the non-viability of a particular class of the F_2 zygotes (as is the explanation offered for both the yellow mice and Antirrhinum);* (2) to selective fertilization, i. e., to a selective union of the gametes; (3) to a disproportionate production of the two kinds of gametes; or (4) to a differential viability of the zygotes, but without the complete disappearance of any one class. That the aberrant ratio in pigeons is not due as in yellow mice to the complete failure of a particular class to materialize is evident at first glance. For not only did we have homozygous dominants (6 A and 7 A) to start with, a thing unknown in yellow mice, but at least one F_2 individual (454 B) was shown to be homozygous for black, and there were others in which this was a probability, but the breeding evidence has been insufficient for proof.

A selective union of gametes rather than union based entirely on chance has been suggested in some cases to account for modified ratios. If we assume that the heterozygote produces *B* and *b* gametes in equal numbers, but that there is an associative mating of the gametes having an intensity of two-thirds, a 2 : 1 ratio will result. In other words, this means that of every three gametes two unite with their own kind and only one with the opposite kind; of three *B*-spermatozoa 2 unite with *B*-ova and 1 unites with a *b*-ovum, while similarly of the *b*-sperms 2 unite with *b* and 1 with *B*. As a result the progeny would have the composition 2 *BB* : 2 *Bb* : 2 *bb*, or 2 blacks to 1 red. But aside from the fact that no sufficient proofs have ever been adduced for a selective union of this sort among the gametes, the results are contrary to the findings in the present case since they give an expectation of equal numbers of homozygous and heterozygous individuals among the dominant forms, while the breeding evidence would seems to indicate that if anything the proportion of *BB* blacks was less than the ordinary expectation of one in three. Furthermore, when a *Bb* individual is mated to a recessive *bb*, there would be no chance for associative mating and consequently a 1 : 1 ratio should ensue. The results (second part of Table III) show an excess of reds.

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*A similar explanation is given by Morgan (1912) to a modified sex-ratio in Drosophila, in which a ratio of 2 ♀ ♀ : 1 ♂ was obtained.

In attempting to explain the occurrence of association of characters Bateson and Punnett (1911) have assumed a differential production of the different kinds of gametes, and a similar assumption might be made in the present case. There is this difference, however, that they assume an unequal production of gametes with respect to the different *combinations* of factors, the number of gametes bearing the antithetic members of an allelomorphic pair being equal, while we are here assuming that greater numbers of gametes are produced bearing one member of the allelomorph than there are bearing the other. Below are shown the proportions of black and red offspring that would result from the fortuitous meetings of *B* and *b* gametes produced in the proportions indicated.

Proportion of *B* : *b* gametes produced	RESULTING OFFSPRING	
	Black	Red
2:3	16	9
3:4	33	16
4:5	56	25
5:6	85	36
5:7	95	49

Only ratios have been selected which give an approximation to a 2:1 ratio, and the tabulation has not been carried further since there is no simple ratio of *B* to *b* gametes which would give a 2:1 ratio of progeny. The nearest of those shown is 3:4, which gives 33 blacks to 16 reds. Assuming in the present instance that the gametes were produced in this proportion, in 83 + 41 = 124 offspring the expectation would be 83.51 blacks to 40.49 reds, which is very close to the actual numbers obtained. Applying this same assumption now to the matings of heterozygous black ♂ to red ♀ and red ♂ to heterozygous black ♀, we have the following (*cf.* Part 2 of Table III):

	OBTAINED			EXPECTED		
MATINGS	Black		Red	Black		Red
♂ *Bb* (black) / ♀ *bb* (red)	16	:	19	15	:	20
♂ *bb* (red) / ♀ *Bb* (black)	6	:	9	6.43	:	8.57
Combined	22	:	28	21.43	:	28.57

Here again the results are surprisingly close to expectation. It is the more surprising since there appears to be no reason for assuming such a disproportionate production of gametes beyond the fact that such an assumption fits so well the observed facts. An assumption of this nature, is, moreover, fundamentally opposed to the basic conception of Mendelian segregation. The only way to reconcile the two would be to suppose that the gametes were formed in equal numbers, but that for some reason one out of four of the *B* gametes became functionless. Bond (1913) believes he has evidence for modified gametogenesis in the case of regenerated testes, with a corresponding modification in the ratio of offspring produced; but the case is far from convincing.

Examining the ratios assumed above as to their probability we get the following:

Numbers obtained $= 83\ B : 41\ b$.
Numbers expected on assumption of 33:16 ratio $= 83.51\ B : 40.49\ b$.
Deviation of observation from expectation $= 0.51$.

P. E. $= \pm 3.522$.

$$\frac{\text{Dev.}}{\text{P. E.}} = 0.144$$

Numbers obtained $= 20\ B : 28\ b$.
Numbers expected on assumption of 3:4 ratio $= 20.57\ B : 27.43\ b$.

Deviation of observation from expectation = 0.57.

P. E. = ± 2.312.

$$\frac{\text{Dev.}}{\text{P. E.}} = 0.246.$$

The ratio of deviation to probable error is in each case less than 1 and consequently both ratios obtained may be assumed to fall very close to expectations on the assumption made.

One further point in which the assumption just made appears to accord with the facts is in the relative numbers of *BB* and *Bb* blacks obtained from matings of heterozygous birds. Under normal conditions it is of course 1 *BB* : 2 *Bb*; under the condition assumed, of 3 *B* to 4 *b* gametes, it would be 9 *BB* : 24 *Bb*, i. e., a relatively larger number of *Bb*. While it has been impossible to test any large number of F_2 birds, the constitution of 10 F_2 blacks has been ascertained through breeding. Of these 9 were *Bb*, while only one was sufficiently proven to be homozygous for *B*. This should not be taken as indicating, however, that the real ratio was anything like as small as 1 *BB* : 9 *Bb*, since the constitution of the two types cannot be determined with equal facility. If a black be mated with a heterozygous black or a red, and a red offspring be produced, it is known at once that the bird was heterozygous for *B*. But if it has only black offspring, a very considerable number must be produced before it can be decided with any great degree of certainty that the bird is homozygous. For example two dun birds (♂ 109 B × ♀ 161 B), F_1's from a dun-yellow cross, were mated and produced 11 dun offspring before there was a single yellow. According to expectation there should have been 3 yellows by this time. In this case the birds were known from their breeding to be *Bb*, but if they had been F_2 birds being tested, and the mating had come to an end at the time 11 offspring had been procured, the formulæ of the parents could only have been recorded as doubtful, although there would of course have been a strong presumption that at least one of them was homozygous. When it is considered that from relatively few of the pigeons raised can so many as

11 offspring be reared to the point where their plumage-color can be determined, in matings that would serve as tests, it will readily be understood why so many of them have to remain recorded as doubtful with respect to whether they are homozygous or heterozygous for dominant characters.

There still remains one possibility to consider, viz.: a different viability of the different classes, but without the complete disappearance of any one class. In this instance it would mean that there is a greater mortality among the B-bearing zygotes prior to the stage at which color of plumage can be determined than among the bb zygotes. This is a question which would be susceptible to experimental investigation were we able to deal with larger numbers, but in the experiments so far as they have gone there appear to be no facts in its substantiation beyond the general one, that if true it would accord with the results obtained.

Other Matings Involving B. In addition to the experiment detailed above, which was for the special purpose of studying the inheritance of black and red, the B factor has naturally been involved in many other matings which have been made for other purposes. These have been brought together, and the results are shown in the accompanying tables. They were originally tabulated with respect to both the B and I factors and the data are presented in this form, and then assembled for the present purpose in Table XII. The birds included in these tables comprise not only selfs, including blues and silvers, but also those with special patterns, and their crosses. Matings of selfs with whites and the mating of the resulting splashed birds are, however, not incorporated, since many of these birds in our stock contain the sex-linked factor which inhibits the appearance of B, mentioned on p. 326, and hence it is not in these cases always possible to be positive simply because a bird is red that B is not present.

TABLE IV.—*Results of matings giving an expectation of 3 BI : 1 bI* (exclusive of those in Tables II and III).

MATINGS	OBTAINED *BI*	*bI*
31 A × 33 A	10	6
292 B × 380 X	1	0
948 B × 835 A	1	1
996 B × 938 B	4	2
1148 C × 1148 A	4	1
1183 A × 1104 B	3	0
Total	23	10
Expected	*24.75*	*8.25*

TABLE V.—*Results of matings giving an expectation of 3 Bi : 1 bi.*

MATINGS	OBTAINED *Bi*	*bi*
32 A × 33 A	3	0
109 B × 161 B	24	4
Total	27	4
Expected	*23.25*	*7.75*

TABLE VI—*Results of matings giving an expectation of 3 BI : 3 Bi : 1 bI : 1 bi (=3 B : 1 b).*

MATINGS	OBTAINED *BI*	*Bi*	*bI*	*bi*
822 B × 818 A	1	2	1	0
841 A × 799 B	1	1	1	1
841 A × 938 B	0	0	0	1
860 A × 432 B	0	1	0	1
901 B × 890 B	4	1	1	1
962 A × 915 B	2	2	3	0
1062 A × 799 A	1	0	0	1
1091 D × 1091 H	1	0	0	0
1091 G × 1266 C	0	2	0	0
1091 L × 1091 S	0	0	0	1
1091 T × 1092 A	1	3	0	0
1092 B × 1091 B	3	4	2	1
1093 A × 1093 B	2	1	0	0
1122 B × 799 B	1	0	0	1
1282 B × 1091 F	0	1	1	0
1282 B × 1266 C	1	0	0	0
Total	18	18	9	8
Expected	*19.88*	*19.98*	*6.62*	*6.62*
Total *B* : *b*	36		17	
Expected B : *b*	39.75		13.25	

TABLE VII—*Results of matings giving an expectation of 9 BI : 3 Bi : 3 bI : 1 bi (=3 B : 1 b).*

	Obtained			
MATINGS	*BI*	*Bi*	*bI*	*bi*
26 A × 27 A.........	12	3	3	1
836 A × 875 A.........	1	0	0	0
862 A × 862 B.........	8	1	2	1
1091 J × 1273 A.........	1	0	1	0
1257 A × 000 C.........	2	1	3	0
1273 G × 1273 C.........	1	0	1	0
Total................	25	5	10	2
Expected.............	*23.625*	*7.875*	*7.875*	*2.625*
Total B : b........	32*		12	
Expected B : b.....	*33*		*11*	

*Includes two offspring in mating 26 A × 27 A not shown in upper part of table. These are recorded as having *B*, but it is uncertain whether they were intense or dilute.

TABLE VIII—*Results of matings giving an expectation of 1 BI : 1 bI* (Exclusive of those in Table III).

	Obtained	
MATINGS	*BI*	*bI*
30 A × 48 B..............................	8	4
157 A × 723 A..............................	9	8
493 B × 701 A..............................	2	0
545 X × 904 B..............................	1	0
887 A × 903 B..............................	4	0
892 A × 892 B..............................	3	0
895 A × 901 A..............................	1	0
932 A × 71 A..............................	3	1
998 A × 56 A..............................	0	1
Total..............................	31	14
Expected..............................	*22.5*	*22.5*

TABLE IX—*Results of matings giving an expectation of 1 Bi : 1 bi.*

	Obtained	
MATINGS	*Bi*	*bi*
32 A × 3 A..............................	7	1
32 A × 673 A..............................	0	2
Total..............................	7	3
Expected..............................	*5*	*5*

TABLE X—*Results of matings giving an expectation of 1 BI : 1 Bi : 1 bI : 1 bi (= 1 B : 1 b).*

	Obtained			
MATINGS	*BI*	*Bi*	*bI*	*bi*
14 A × 35 A..........	2	1	2	3
32 A × 34 A..........	1	1	0	0
32 A × 559 B..........	4	1	0	0
450 X × 450 Y..........	4	1	2	0
568 B × 398 A..........	0	0	1	0
763 A × 380 X..........	0	1	0	1
769 A × 1209 B..........	0	4	2	1
875 B × 924 B..........	1	1	1	0
913 A × 846 B..........	0	0	1	1
913 A × 932 B..........	0	0	1	0
925 A × 904 A..........	2	4	1	3
Total................	14	14	11	9
Expected............	*12*	*12*	*12*	*12*
Total *B* : *b*........	28		20	
Expected B : b.....	*24*		*24*	

TABLE XI—*Results of matings giving an expectation of 3 BI : 1 Bi : 3 bI : 1 b i (= 1 B : 1 b).*

	Obtained			
MATINGS	*BI*	*Bi*	*bI*	*bi*
60 B × 34 A...........	1	1	1	1
646 A × 356 A...........	2	1	1	1
656 A × 719 B...........	1	0	1	0
656 B × 867 B...........	2	0	3	0
681 B × 701 A...........	2	1	1	1
725 A × 664 B...........	1	0	1	1
798 A × 836 B...........	2	0	4	3
828 A × 806 B...........	1	2	1	0
966 B × 796 A...........	3	0	4	0
Total................	15	5	17	7
Expected............	*16.5*	*5.5*	*16.5*	*5.5*
Total *B* : *b*........	20		24	
Expected B : b.....	*22*		*22*	

TABLE XII—*Summary of matings showing ratio of B : b.*

EXPECTATION 3 *B* : 1 *b*			EXPECTATION 1 *B* : 1 *b*		
	B	*b*		*B*	*b*
Table IV	23	10	Table VIII	31	14
Table V	27	4	Table IX	7	3
Table VI	36	17	Table X	28	20
Table VII	32	12	Table XI	20	24
Total	118	43	Total	86	61
Expected	*120.75*	*40.25*	*Expected*	*73.5*	*73.5*
Table III	56	32	Table III	22	28
Table III	27	9			
			Expected	*25*	*25*
Total	83	41			
Expected	*93*	*31*			
Grand total	201	84	Grand total	108	89
Expected	*213.75*	*71.25*	*Expected*	*98.5*	*98.5*

For the time being we will consider only the relation of *B* to *b* offspring in the above tables, and first those giving an expectation of 3 *B* : 1 *b*. In Tables IV, VI and VII we find an agreement with our former results in that in each case there is a slightly smaller number of *B* birds than expected. Table V, on the other hand, shows an excess of *B*. The total of 118 *B* to 43 *b* is fairly close to 3:1. If these are combined with the results from Tables II and III as is done in Table XII there is a resulting grand total of 201 *B* to 84 *b* birds, which is still a deficiency of *B* offspring.

The results of matings giving an expectation of 1 *B* : 1 *b* are on the other hand quite different in these tables from those in Table III. There, there was an excess of reds proportional in amount to the excess in the 3:1 ratios; but in Tables VIII, IX and X *B* is in considerable excess, while in Table XI the excess of *b* over *B* is very small. The totals show a ratio of 86 *B* : 61 *b*. Even when these results are combined with those of Table III the *B* birds are still considerably in excess.

There seems to be no obvious explanation of these divergent results. The most probable explanation seems to be that there is a tendency toward the production of different ratios in different "families," "family lines," or "strains" of our pigeons. In the birds used in the black-red experiment, all of which came from a single pair of reds and a single pair of blacks, there seemed to be a definite tendency to an over-production of reds. The duns ♂ 109 B and ♀ 161 B, on the contrary, produced decidedly more than the expected number of duns (see Table V), and the same tendency has been noticed in some of their relatives.

Different genetic tendencies in different strains of the same species or variety do not present any new idea, though no adequate explanation of their cause has been given, except in cases when more than one factor has been assumed, as Wentworth (1913) has done for fecundity in Drosophila. It is doubtful if such an explanation could be given to the differences in sex-ratios found by Rawls (1912) in Drosophila, or for the rather definite percentage of cases of "non-disjunction" described by Bridges (1913) in the same animal. The same is true of the pigeons, where there seems no doubt that in black *vs.* red we are dealing with a case of simple allelomorphism. Whether this is due to an unequal production of the different classes of gametes or whether there is a differential viability of the zygotes it seems to me we are not at present in position to determine. I feel inclined to favor the latter view in spite of the fact that the results of the black-red experiment could be explained so consistently on an assumption of a production of gametes in the proportion of 3 *B* to 4 *b*.

The I-Factor.

The general relations and effects of the *I* factor have already been described (p. 323), and it remains only to consider the ratios obtained. As was stated, although this factor is sex-linked, no attention will be paid to the matter of sex proportion in relation to color in the present treatment. It is only necessary to bear in mind that intense females are always heterozygous for *I*,—that is, they are always *Ii* and can never be *II*. The breeding results have consistently borne out this fact. In bringing together the records for the *I* : *i* ratios all cases have been considered which give a difference in intensity, including special patterns and splashed birds. As has already been remarked (p. 333), whether a bird is intense or dilute may be determined even when the bird is all white except for one or two colored feathers. If the bird is entirely white, its constitution can only be ascertained by breeding tests. The formulæ of such self-white birds have in a number of instances been determined, and the records of these have been included in the present computation. The records as compiled include a large number of matings, and as there appears to be no particular advantage in presenting the results of each in detail they are summed up in Table XIII.

TABLE XIII.—*Results of all matings giving expectations of 3 I: 1 i and 1 I: 1 i.*

Expected Ratio	No. of matings included	Offspring Obtained			Expected	
		Total	*I*	*i*	*I*	*i*
3 *I* : 1 *i*.........	50	242	189	53	181.5	60.5
1 *I* : 1 *i*.........	78	401	207	194	200.5	200.5

Considering first the matings of birds both heterozygous for *I*, when the expectation is 3 intense offspring to 1 dilute, we find that of the 242 young produced 189 were recorded as intense and 53 as dilute. The expectation for this number is 181.5 to 60.5, the deviation of observation from expectation being 7.5. The probable error with this number of individuals is ± 4.54, so that the deviation obtained is 1.6 times the probable error, or the odds are slightly against the chance occurrence of a deviation as great or greater than this, being 2.57 to 1. We may nevertheless, reasonably consider that 3:1 is the real ratio, especially when one or two facts are taken into consideration which may in part account for the slight excess of intense birds recorded. In the early part of the work, before the relations of the colors were understood, more attention was paid as to whether black or red pigment was present in the plumage than to whether it was intense or dilute. It is possible therefore that the color was sometimes recorded as "black," simply meaning that it was not "red." Soon, however, the need of closer scrutiny was appreciated and the observations in this respect became much more critical. At most the number of errors occurring from this cause must have been relatively very small. In a few cases, mostly in one family of related birds, a dun color has been noticed that is darker than is usual on young birds, and as black is less deep in shade in the first plumage, it has happened in a few instances that this dark dun has first been recorded in nestlings as "poor" black, and corrected later. It is possible that a few uncorrected errors of this kind may be included in the final numbers, but again there cannot be many such.

Table XIII records also the results of 78 matings of heterozygous intense birds (*Ii*) to dilutes (*ii*), with 401 resulting offspring. Of these 207 were intense and 194 dilute, the expectation being 200.5 of each. Here the deviation from expectation is 6.5 and the probable error ± 6.75. The ratio of observed deviation to probable error is therefore 0.96 and the odds are in favor of the observed deviation being due to chance.

Here again it will be noticed that the deviation is in favor of the intense condition, and the explanation may be the same as that given above.

From these results it may fairly be concluded that *I* segregates from *i* in a normal Mendelian fashion and that the recombinations occur according to expectation well within the limits of chance.

Illustrative Matings Showing the Relationships of the Different Factors.

Many different matings of birds showing the different characters described in this paper have been made and the subsequent segregation observed. These as a rule, especially in cases of dihybridism and trihybridism, have not been in sufficient numbers to make a statistical consideration of the ratios obtained in the progeny profitable at the present time; but it may help to make their relationship convincing to present a number of illustrative matings in order to show that the facts bear out the hypothesis, in so far as they go, in that the expected classes are obtained. The relation of black and red has already been illustrated by the experiment given in detail and need not be mentioned further. The colors have a simple monohybrid relation, though the ratios may for some reason be disturbed. In that experiment all the birds used were intense. The relation of *B* to *b* in dilute birds is shown in the following cross:

		dun	yellow
♂ 32 A — *Bbii* — dun ♀ 3 A — *bbii* — yellow	produced	7	1*

If 32 A had been homozygous for *B*, the expectation would, of course, have been all dun offspring. The bird was purchased and his exact breeding as to colors was unknown; but that he was in reality a *Bb* bird was further proven by the fact that he later produced two yellow offspring when bred to a different yellow female. Two of the dun offspring of the above mating, both of which proved to be heterozygous for *B*, were mated with the following result:

		dun	yellow
♂ 109 B — *Bbii* — dun ♀ 161 B — *Bbii* — dun	produced	24	4

Black being dominant to red and intense dominant to dilute, black offspring would be expected from crossing black and yellow, provided, of course, that the black bird is homozygous for *B* and *I*. If it is heterozygous for *I*, duns should appear in addition to blacks; if heterozygous for *B*, there should be blacks and reds; while if both are heterozygous all four classes should appear. That these results are obtained is shown by the matings in Table XIV.

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*This individual was, at the time of its death when 18 days old, recorded as apparently going to be red. As it was under-nourished and probably poorly feathered even for that age, however, it seems fair to assume in view of the statement on p. 360, that red should be interpreted here as merely meaning that the pigment was not black or dun, and that the color was really yellow as would be expected.

TABLE XIV—*Matings of Black with Yellow.*

	MATINGS	Black	Dun	Red	Yellow
1.	♂ 662 A — *B(B)II** — black ♀ 673 A — *bbii* — yellow	2	....	....	....
2.	♂ 731 A — *BBII* — black ♀ 685 A — *bbii* — yellow	7	....	....	....
3.	♂ 691 A — *BBII* — black ♀ 724 A — *bbii* — yellow	5	....	....	....
4.	♂ 825 A — *BBII* black ♀ 932 A — *bbii* — yellow	3	....	....	....
5.	♂ 58 B — *BBIi* — black ♀ 645 B — *bbii* — yellow	4	4	....	....
6.	♂ 473 A — *bbii* — yellow ♀ 650 A — *BBIi* — black	4	3	....	....
7.	♂ 157 A — *BbII* — black ♀ 723 A — *bbii* — yellow	9	....	8	....
8.	♂ 925 A — *BbIi* — black ♀ 904 A — *bbii* — yellow	2	4	1	3

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*The inclusion of a factor in parentheses in a formula indicates uncertainty as to its presence.

Below are shown the F_2 results of matings of F_1 birds from black-yellow crosses. The first pair are two of the five F_1 blacks produced in mating No. 3 of Table XIV. The second pair are a black and a dun from mating No. 6 of the same table. The blacks being heterozygous for both *B* and *I* and the dun for *B*, all four classes of young were to be expected.

		black	dun	red	yellow
♂ 862 A — *BbIi* — black ♀ 862 *B* — *BbIi* — black	produced	8	1	2	1
♂ 841 A — *BbIi* — black ♀ 799 B — *Bbii* — dun	produced	1	1	1	1

Red to yellow gives all red when the red parent is homozygous for *I*.

♂ 1 A — *bbII* — red
♀ 4 A — *bbii* — yellow
produced 9 offspring, all red.

If the red parent is heterozygous for *I*, both red and yellow offspring are obtained. Three such matings gave a total of 14 red to 9 yellow. A single mating may be given by way of illustration.

		red	yellow
♂ 656 B — *bbIi* — red ♀ 709 A — *bbii* — yellow	produced	4	4

Reds and yellow are produced also when both parents are red and heterozygous for intensity.

		red	yellow
♂ 725 A — *bbIi* — red ♀ 726 A — *bbIi* — red	produced	5	1

When red and dun are crossed one dominant character is brought in from each parent and the resulting offspring are accordingly all black, provided the parents were homozygous. If the red parent is heterozygous for intensity both black and dun birds will occur in the progeny. Both these conditions are illustrated in the following matings.

		black	dun
♂ 1 A — *bbII* — red ♀ 903 A — *BBii* — dun	produced	7	0
♂ 540 B — *BBii* — dun ♀ 448 B — *bbIi* — red	produced	4	2

In case both parents are heterozygous for their respective dominant characters, all four classes, black, dun, red and yellow are expected. In the following mating, which is of this character, no yellow was obtained, but this is scarcely surprising considering that only 8 young were reared.

		black	dun	red	yellow
♂ 450 X — *Bbii* — dun ♀ 429 Y — *bbIi* — red	produced	4	1	3	0

The F_1 blacks obtained in these matings have the composition *BbIi*, the same as the F_1 birds from the mating of black × yellow (see Table XIV) and should similarly produce blacks, duns, reds and yellows when bred together. No mating appears to have been made, however, of F_1 blacks obtained from a red-dun cross.

Homozygous black mated to homozygous blue[†] gives all black in F_1, and an expectation of 3 black to 1 blue in F_2. The blue male 999 A used in the illustrative example was a wild Rock Pigeon,[*] and the mating shows the dominance of the black of the domesticated variety over the ancestral blue.

♂ 999 A — *BBIIss* — blue Rock Pigeon ♀ 7 A — *BBIiSS* — black	produced 10 offspring, all black.

Two pairs of these F_1 birds have given the following:

		black	blue
♂ 1033 A — *BBIISs* — black ♀ 1033 B — *BBIiSs* — black	produced	4	1
♂ 1033 D — *BBIISs* — black ♀ 1033 E — *BBIiSs* — black	produced	8	1
		12	2

Black crossed with silver gives all blacks when the black parent is homozygous; if it is heterozygous for *I*, blacks and duns are produced. Both these conditions are illustrated in the following matings.

		black	dun
♂ 6 A — *BBIISS* — black ♀ 639 B — *BBiiss* — silver	produced	7	0
♂ 639 A — *BBiiss* — silver ♀ 719 B — *BbIiSS* — Black	produced	3	2

In F_2 blacks, duns, blues and silvers should be produced. The birds in the first mating below are F_1's from 6 A × 639 B; those in the second mating are from 639 A × 719 B.

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[*] The Rock Pigeons which we have used in our experiments were obtained from the collection of the late Prof. C. O. Whitman through the kindness of Dr. Oscar Riddle. It is a pleasure to acknowledge our indebtedness to him for these birds.

[†] Blue and silver as referred to in this paper mean blue-barred and silver-barred, and do not include the so-called blue-check, etc.

		black	dun	blue	silver
♂ 905 B — *BBIiSs* — black ♀ 864 A — *BBIiSs* — black	produced	5	2	0	1
♂ 915 A — *B(B)IiSs* — black ♀ 837 A— *B(B)IiSs* — black	produced	4	4	1	3

Blue crossed with red gives all black offspring, as would be expected, provided the red parent is homozygous for *S*, the blue for *B*, and one or both for *I*.

♂ 999 A — *BBIIss* — blue Rock Pigeon ♀ 701 A — *bbIiSS* — red	produced 3 blacks.

Silver with red should similarly give all black offspring if the parents are homozygous. In the following matings, however, the red parents were heterozygous for intensity, consequently both blacks and duns were produced.

		black	dun
♂ 639 A — *BBiiss* — silver ♀ 2 A — *bbIiSS* — red	produced	1	2
♂ 697 A — *BBiiss* — silver ♀ 701 A — *bbIiSS* — red	produced	7	7

The black F_1 birds from these matings are heterozygous for all three factors, while the duns are heterozygous for *B* and *S*. As a consequence, in matings of black to black or black to dun, all six different colors described in this paper are obtained in F_2. The following examples show only matings of F_1 blacks to duns of the same generation, which gives an expectation of 9 black : 9 dun : 3 blue : 3 silver 4 red : 4 yellow.

		black	dun	blue	silver	red	yellow
♂ 1092 B — *BbIiSs* — black ♀ 1091 B — *BbiiSs* — dun	pro.	3	2	0	2	2	1
♂ 1091 D — *BbIiSs* — black ♀ 1091 H — *BbiiSs* — dun	pro.	0	0	1	0	0	0
♂ 1091 L — *BbIiSs* — black ♀ 1091 S — *BbiiSs* — dun	pro.	0	0	0	0	0	1
		3	2	1	2	2	2

That silver mated to yellow produces duns as would be expected is shown by the following mating:

♂ 697 B — *BBiiss* — silver
♀ 709 A — *bbiiSS* — yellow
produced 5 dun offspring.

The cross of blue with yellow brings in all the dominant factors and gives black offspring if the parents are homozygous. In the first mating given below the yellow female was apparently heterozygous for S, while in the second the male was heterozygous for *I*.

♂ 999 A — *BBIIss* — blue
♀ 723 A — *bbiiSs* — yellow
produced 2 black, 1 blue.

♂ 36 A — *BBIiss* — blue
♀ 21 B — *bbiiSS* — yellow
produced 7 black, 10 dun.

Matings of blue and silver involve only the intensity factor when both are homozygous for *B*. When the intense parent is homozygous for *I* all the offspring are blue; but if it is heterozygous for *I*, both blues and silvers are obtained as illustrated in the mating here given.

		blue	silver
♂ 39 A — *BBiiss* — silver ♀ 245 A — *BBIiss* — blue	produced	6	5

While the above are not all of the possible matings that might be made, they are sufficient, I believe, to demonstrate that the factors and their relationships as postulated are adequate to meet the facts brought out in the experiments in so far as they go.

The Inheritance of White.

The suggestion has already been made that white in pigeons is dependent upon a number of factors (see p. 331). In the discussion which follows only enough illustrative matings will be given to demonstrate the probability of this assumption. The number of data available at present are scarcely sufficient to warrant any serious attempt at a mathematical treatment. In the tabulations which follow no attention has been given to the particular color which may be present in splashed birds, but only to the relative proportion of white and colored plumage. Furthermore, the classifications in this respect are only rough approximations, since it is extremely difficult in some cases to judge of the proportional amount of pigmented plumage from a description, especially if that particular point were not in mind at the time the description was made. More recently drawings have been kept of all splashed birds as well as of those with definite patterns, and in other cases photographs are at hand, or the skins have been saved. When such records are available it is much easier to distribute the birds into their respective categories.

Other disturbing elements which enter are the difference in amount of splashing at different ages and the fact that young birds often appear to be self white when half feathered or more, but when the feathers are fully out they may show some pigment. Squabs dying before fully feathered have often been recorded as "apparently going to be self white" or "self white so far as can to told." Such records have been included in the "self white" column in the tabulations, and the fact that they were young at the time the description was made is noted. On the other hand birds which have considerable pigmentation in the juvenal plumage may later molt out to completely or practically white. This is especially true of color in the flight feathers, while splashes on the head and neck often become more definite and remain. Conversely some birds which are self white even in the earlier post-juvenal plumages may at later molts acquire a few pigmented feathers, Since, in many instances, descriptions of the juvenal plumage only are available, this stage has been used in all cases when possible in grouping the birds.

It will be noted that in spite of the difficulties of exact classification seven groups have been made. At one extreme are self-white birds; next come those which are white except for a few colored feathers; then birds with much color, but still with a predominance of white; then in order those with white and color in approximately equal amounts; color in excess of white; all colored except for a small amount of white; and finally, at the opposite extreme, self-colored birds which have no white feathers at all. For convenience the classes are numbered from 1 to 7 in the order here given. Although the classification into these groups is by no means exact, the tables serve to indicate, nevertheless, in a general way, the distribution of young from different matings.

The fact has already been mentioned (p. 329) that at least in Tumblers white birds seldom if ever breed absolutely true, that is always produce self-white offspring and never any with "foul" feathers in the plumage. This is illustrated in the first section of Table XV, which gives the distribution of offspring of 12 A × 10 A, both of which were self-white birds. It will be noted that the progeny are all grouped towards the "white" end of the series, but of the 17 offspring only 11 are recorded as self-white, and of these 4 were described when very young and might later have shown some colored feathers. On the other hand, in column 2, "white with colored feathers," there are five birds, two of which are known later to have become self-white. Finally, there is one bird in Class 3, which means that there was a considerable amount of color in the plumage.

TABLE XV.—*Results of crossing Whites together and to Self-Colored Birds.*

PARENTS	OFFSPRING						
	1 Self white	2 White (c. f.)	3 White > color.	4 White= color.	5 White < color.	6 Colored (w. f.)	7 Self colored.
♂ 12‡ A — Self white — Class 1 ♀ 10 A — Self white — Class 1	81 A 81 B* 95 B* 154 A 154 B 198 B 234 B 317 A 317 B* 362 A* 387 B	117 A† 117 B 198 A† 234 A 387 A	362 B				
♂ 12 A‡ — Self white — Class 1 ♀ 2 A‡ — Self red — Class 7	495 B*		459 B§ 482 B§	459 A§ 482 A§			
♂ 12 A‡ — Self white — Class 1 ♀ 3 A — Self yellow — Class 7			40 B 61 B 70 B	61 A	50 B		40 A
♂ 40 A — Self red — Class 7 ♀ 40 B — White spl. — Class 3			97 A 173 B 268 A 297 A	201 B	173 A 206 B 297 B	143 A 206 A 233 B	121 A 121 B* 143 B* 233 A

*Very young when description taken.
†Later became self white.
‡See photograph on Plate II.
§See photograph on Plate III.

In the second part of the table we have the same male (12 A) mated to a self-red female (2 A), both of which are figured on Plate II. One of the young is recorded as self white, but it was young when described; the other four fall in Classes 3 and 4 and consequently had considerable color in the plumage. An idea of the amount of splashing on these birds may be gained from the photographs (Pl. III, Figs. 10–13). In the next section of the table 12 A is again mated to a self-colored female, this time a self yellow (3 A). Three of the offspring fall in Class 3, one each in Classes 4 and 5, and one is completely colored (♂ 40 A, self red, Class 7). Finally, in the lowest section of the table we have this F_1 self red (40 A) mated to his nest mate (40 B), which was a splashed bird, belonging in Class 3. From them 15 young were reared and the tendency of these to have a large amount of color is very noticeable.

TABLE XVI.—*Cross of Self White with Splash.*

PARENTS	OFFSPRING						
	1 Self white	2 White (c. f.)	3 White > color.	4 White = color.	5 White < color.	6 Colored (w. f.)	7 Self colored
♂ 9A — Self white — Class 1	91 A	43 A	52 A	66 A	66 B	74 A	
	91 B	52 B	377 A			105 A	
♀ 13A — White spl. — Class 2	105 B	74 B	377 B				
	156 A	135 B†	438 A				
	156 B	191 A					
	191 B	219 A					
	251 A	278 B					
	278 A*	576 X					
	311 A*	576 Y					
	311 B						
	350 X*						
	350 Y						
	399 A						
	399 B*						
	417 A						
	438 B						
	461 A						
	474 A*						
	474 B*						
	490 A*						
	490 B*						
	548 A						
	548 B*						
	607 A*						
	607 B*						

*Young when described.
†Later became self white.

Table XVI shows the results of a mating of a self white male (9 A) with ♀13 A, which was self-white except for a few yellow feathers on the head and breast. The male has a "bull" eye on the left side, but the right eye was that of a normal Tumbler (see Pl. II, Figs. 6 and 7), and there were no foul feathers in the plumage. "Bull" eye might be taken to indicate a locus of pigmentation at this point corresponding to a splash in the plumage, but no direct relationship has been established. Apparently it is a condition independent of the factors which cause the plumage pigmentation; if anything there appears to be a tendency for "bull" eye to accompany white plumage (*cf.* p. 330). Forty-four young resulted from this mating, of which 25 fall in Class 1, 9 in Class 2, 4 in Class 3, 1 each in Classes 4 and 5, and 2 in Class 6.

TABLE XVII.—*Mating of Self-Whites and of their Splashed Offspring.*

PARENTS	OFFSPRING						
	1 Self white	2 White (c. f.)	3 White> color.	4 White= color.	5 White< color.	6 Colored (w. f.)	7 Self colored.
♂ 15 A — Self white — Class 7 ♀ 10 A — Self white — Class 1	65 A*		41 A 41 B 51 A 65 B	51 B			
♂ 41 A — White spl. — Class 3 ♀ 51 A — White spl. — Class 3		216 A	111 B 163 A 183 A 183 B 216 B 237 A (264 B?)	163 B 237 B	264 A		
♂ 41 B — White spl. — Class 3 ♀ 51 B — White spl. — Class 4				110 B 218 A	186 A		164 B 186 B

*Young when described.

In the first part of Table XVII are shown the results of crossing a self yellow male (15 A) with a self-white female (10 A—compare with first part of Table XV, where this female was shown mated to a self-white male). While one young bird was recorded as "white," the other 5 offspring fell in Classes 3 and 4. The matings of two pairs of these F_1 birds are given in the remaining two sections of the table. In the middle section is the mating of 41 A and 51 A, both of which were themselves in Class 3, and it will be seen that the larger number of their progeny fall in the same class. Below this is a mating of 41 B (Class 3) with 51 B (Class 4), and of the 5 offspring produced 2 were self colored, while none was lighter than the darker parent.

TABLE XVIII.—*Mating of White Splash with Self Yellow.*

PARENTS	OFFSPRING						
	1 Self White	2 White (c.f.)	3 White> color.	4 White= color.	5 White< color.	6 Colored (w. f.)	7 Self color.
♂ 660A — White spl. — Class 5 ♀ 645A — Self yellow — Class 7					1061 C* 1061 E* 1061 K*	1061 B* 1061 H*	1061 A 1061 D* 1061 F 1061 G 1061 J

*Photograph reproduced on Plate IV.

A mating of a bird with much color (660 A, Class 5) with a self yellow female (645 A) is presented in Table XVIII. Here it will be noticed that 5 of the 10 young produced are self-colored, 2 are nearly so, and 2 have more pigment than white. None has more white than color. The range of variation in these birds is shown in the photographs (Pl. IV, Figs. 14–19).

It seems clear from the discussion of the tables, and in fact from simple inspection of the tables themselves, that in general there is a tendency for the offspring to be grouped about the mean condition of their parents with respect to the amount of pigmentation in the plumage. In this respect the inheritance of white coincides with those cases which were formerly given as examples of blending inheritance, but which are now more generally attributed to multiple factors. There appear to be some reasons for the latter hypothesis, the evidence for which cannot be presented at this time, but which we hope to bring forward later when our data are more complete. The statement may be made simply that in all probability there is no definite distinction in kind between the factors for white concerned in the splashed bird and most of those which are responsible for the white in the case of definite patterns, such as Rosewing, Mottle, Baldhead, Saddle, and the like. On the contrary there may be more or less tendency to localization of action in the zygote of all the *W*-factors, in which case patterns would come about by a condition approaching homozygosity for factors acting in certain definite regions and the absence of other factors which would affect other regions. The degree to which birds would breed true to any pattern would accordingly depend upon how closely their factorial composition approached such homozygosity. In case this hypothesis is correct it should be possible to separate out and identify many of these factors by breeding experiments, and as their analysis progressed, what at first was regarded as multiple factors would assume more the nature of interacting factors as we know them in so many cases. For this reason also the classification of the birds simply on the amount of white in the plumage is perhaps not altogether justifiable; nevertheless, in any case it gives a rough approximation of the condition, and may serve to show at least the general nature of the phenomena involved.

In view of the various facts which have been presented, it seems more logical to consider white in pigeons as dependent upon the summation of factors which inhibit pigment formation in the feathers, rather than as a recessive condition.

Summary.

1. The present bulletin is a study of the inheritance of certain colors of Tumbler pigeons and some of their modifications. These colors are red, black, yellow, dun, blue, silver and white.

2. Only two kinds of pigment are concerned, red and black. Red (*R*) is potentially present in all the birds, but shows only when not inhibited and when black (*B*) is absent, since black is epistatic to red.

3. For the full development of intensity of red and black the presence of an intensity factor (I) is necessary. In the absence of this factor these colors remain in the dilute condition, red appearing yellow and black as dun.

4. Another factor necessary for the full expression of black is one (S) which is presumed to cause the pigment to spread throughout the barbules of the feather instead of remaining clumped in the central part of the old barbule cells. When S is absent, and the pigment is clumped as described, the appearance known as blue results. The dilute condition of blue is silver. The factor S affects only black pigmentation and does not produce any difference in the appearance of red, at any rate that has as yet been identified.

5. White in the plumage of pigeons is due to an indefinite number of factors (W_1, W_2, etc.) which inhibit the production of pigment in the areas which they influence.

6. Definite patterns may result from the approach to a homozygous condition for W factors which act on particular definite regions of the plumage.

7. "Reversion" to the wild blue Rock Pigeon type in domesticated pigeons is due simply to a recurrence of the particular combination of factors which are present in *C. livia*.

8. An extensive experiment on the inheritance of black and red showed an over-production of red birds in F_2, the ratio being practically 2:1 instead of 3:1. This is not due to the absence of the homozygous dominant class as in yellow mice. Possible explanations are offered but no definite conclusion is reached.

9. Different strains or family lines appear to have different tendencies as to the ratios of blacks and reds they produce in F_2. Lumping all of the results shows still a slight excess of reds.

10. The ratios of intense to dilute birds from heterozygotes bred to other heterozygotes or to dilutes closely approximate Mendelian expectation, that is 3:1 and 1:1, respectively.

11. Various matings of the different colors give the results expected according to theory. A considerable number of illustrative matings are presented.

12. Illustrations are given of matings of white to white, white to splash, white to self, splash to splash, and splash to self. In general, the offspring tend to be grouped around the parental mean with respect to amount of color in the plumage. The evidence supports the conclusion that a number of factors are concerned in the production of white and splashed birds.

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Description of Plates.

PLATE I.

Fig. 1. Dun pigeon (410 A) showing check markings, for the most part of the "inner vane" type. The rump and light markings of the checks are silvery.

Fig. 2. Wild Rock Pigeon (*C. livia*—1000 A). Blue with black wing bars and black terminal band on tail. Note also the very light rump typical of *C. livia.*

Fig. 3. An ordinary blue Tumbler (26 A). Like the wild Rock Pigeon in color except for the light rump.

Fig. 4. Black bird (182 A) with blue tail and light rump. This is the sort of bird which Staples-Browne referred to as "reversionary blue."

Fig. 5. An extracted blue (1242 A). The parents were a black ♂ from a silver × black mating and a white splash ♀ from a silver × white mating.

PLATE II.

Fig. 6. Right side of head of white ♂ 9 A showing typical Tumbler eye.

Fig. 7. Left side of head of 9 A with "bull" eye.

Fig. 8. Self white ♂ 12 A used in the matings shown in Table XV.

Fig. 9. Self red ♀ 2 A. A mating of this bird with 12 A is given in Table XV. Four of the offspring of this pair are shown in Plate III.

PLATE III.

Four splashed offspring from ♂ 12 A × ♀ 2 A (see Table XV and Plate II).

Fig. 10. No. 459 B (♀), white splashed with yellow. Class 3.

Fig. 11. No. 459 A (♀), white splashed with red. Class 4.

Fig. 12. No. 482 B, white splashed with red. Class 3.

Fig. 13. No. 482 A (♂), white splashed with red. Class 4.

PLATE IV.

Six offspring from mating white splash ♂ 660 A × self yellow ♀ 645 A (see Table XVIII). The appearance of the birds as reproduced here does not correspond exactly with their placing in the table, (1) because they changed somewhat in appearance between the time the early descriptions (upon which the classification is based) were taken and the time of photographing, and (2) because there is on some, for example 1061 C, a light diffusion of pigment over much of the area which appears white in the photograph.

Fig. 14. No. 1061 C, white splashed with reddish. Class 5.

Fig. 15. No. 1061 E, white splashed with black. Class 5.

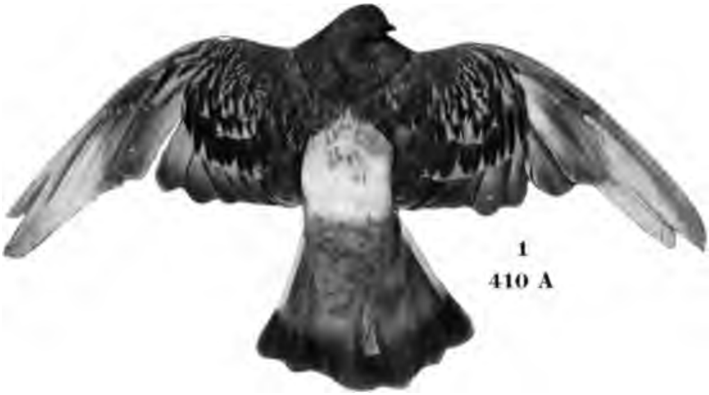
Fig. 16. No. 1061 K, white splashed with black. Class 5.

Fig. 17. No. 1061 B, red with a few white markings. Class 6.

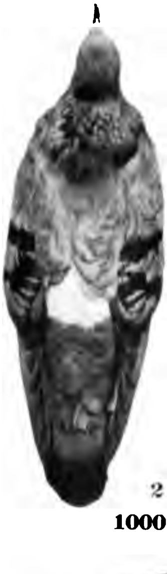
Fig. 18. No. 1061 H, red with white markings (note white upper tail covert). Class 6.

Fig. 19. No. 1061 D, self red. Class 7. The light areas in the photograph are due to the light under color and do not represent white in the plumage.

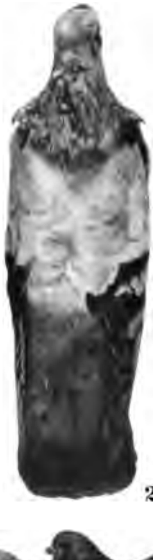
PLATE I



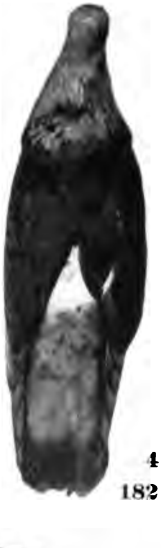
1
410 A



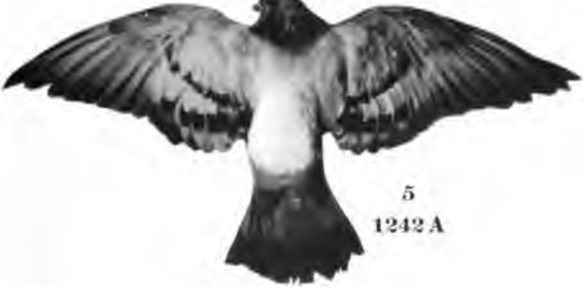
2
1000 A



3
26 A



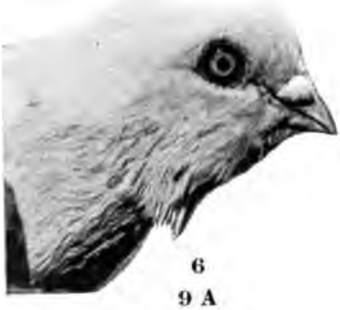
4
182 A



5
1242 A

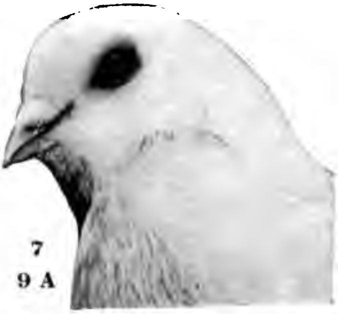
UN

PLATE II



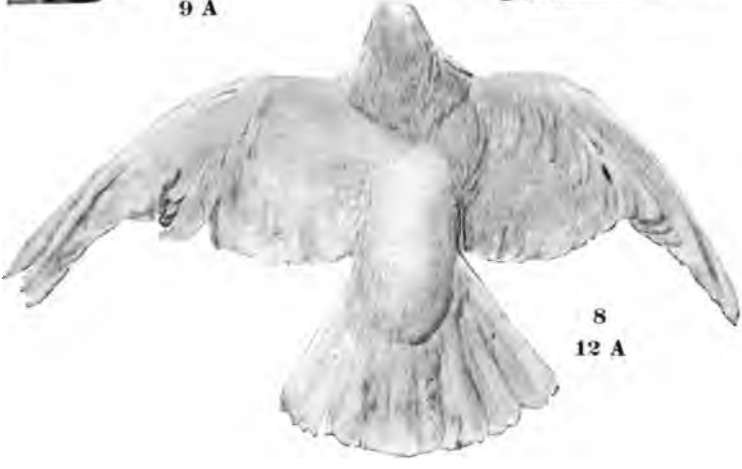
6

9 A



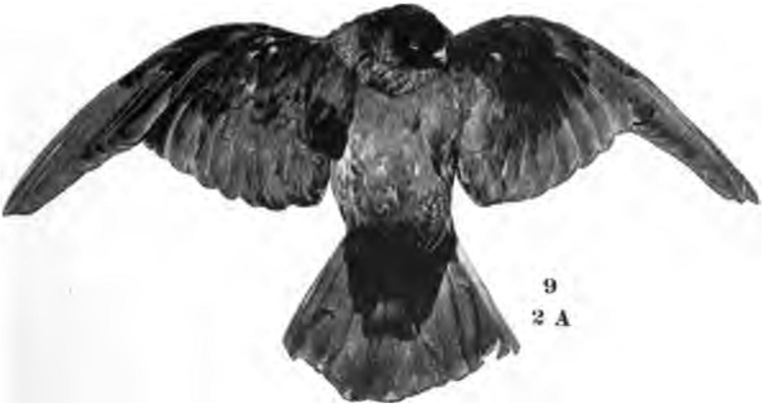
7

9 A



8

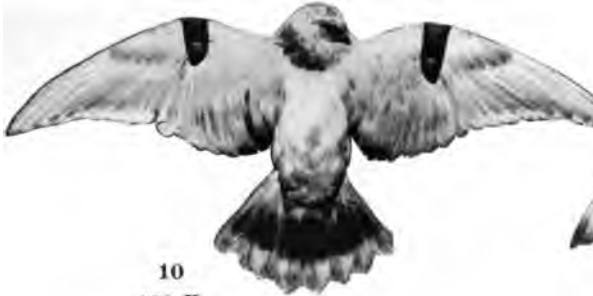
12 A



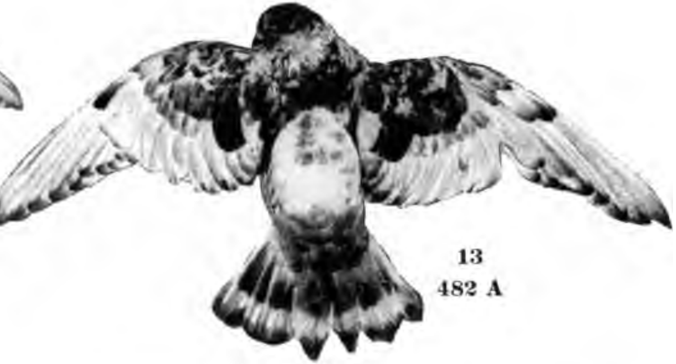
9

2 A

PLATE III



10
459 B



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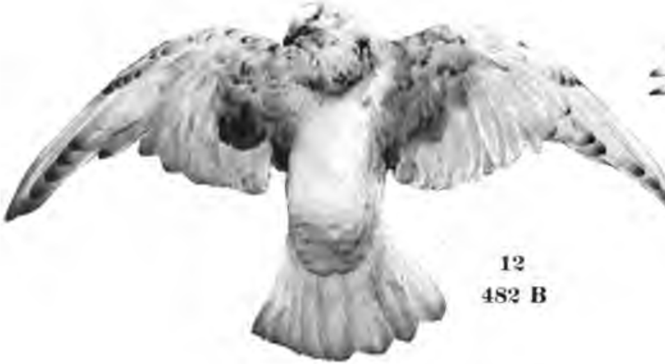
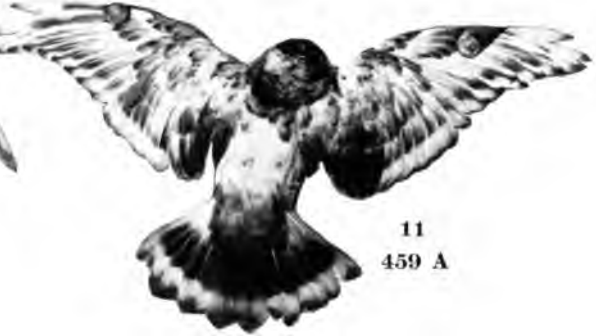
482 A



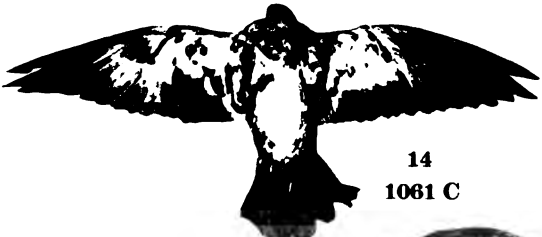
12
482 B



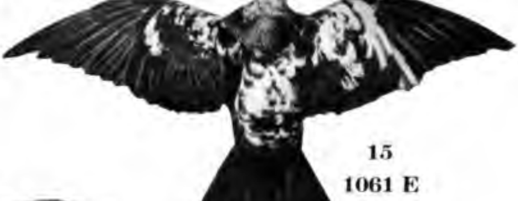
11
459 A

UNIV. OF MIC

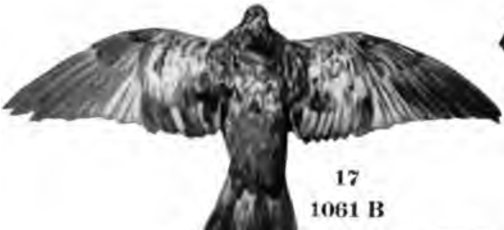
PLATE IV



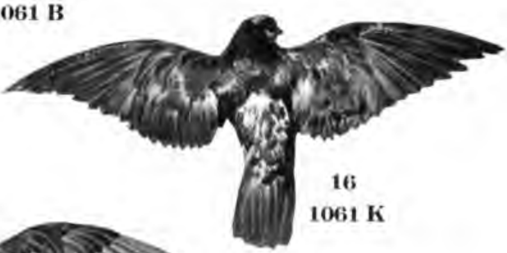
14
1061 C



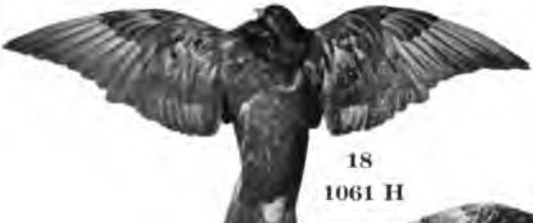
15
1061 E



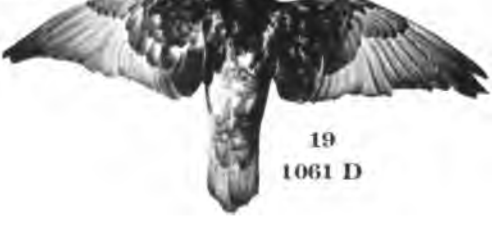
17
1061 B



16
1061 K



18
1061 H



19
1061 D

UNI. N.C.

STUDIES ON FOWL CHOLERA: IV. THE RECIPROCAL RELATIONS OF VIRULENT AND AVIRULENT CULTURES IN ACTIVE IMMUNIZATION.

BULLETIN 159

Agricultural Experiment Station

OF THE

Rhode Island State College

KINGSTON, R. I., U. S. A., JUNE, 1914.

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BULLETIN 159, JUNE, 1914.

STUDIES ON FOWL CHOLERA: IV. THE RECIPROCAL RELATIONS OF VIRULENT AND AVIRULENT CULTURES IN ACTIVE IMMUNIZATION.*

PHILIP B. HADLEY.

In previous papers, the present writer† has described certain aspects of an active immunity produced in rabbits against infection with virulent cultures of the fowl cholera bacterium.

The results were, briefly, as follows: Among nine cultures examined for their resistance-producing power, one was found (Culture 52) which was capable, when inoculated subcutaneously in amounts of at least 0.000,000,01cc., of producing, within one to two weeks, a perfect immunity against any reasonable amount of the most virulent culture obtainable (Culture 48).‡ The inoculation with Culture 52 is followed, usually within two to four days by an induration which later becomes necrotic and eventually undergoes drainage, followed by healing. Immunity against virulent Culture 48 seems to be permanently acquired. In immune females it persists to such a degree that even two and one-half years after immunization they are able to give birth to young rabbits that are immune for about the first forty days of life. In these young animals this inherited immunity can be transformed by means of appropriate inoculations of virulent culture, administered at the proper time, into a permanent active immunity.* Guinea-pigs were rendered perfectly immune to intra-peritoneal inoculation† with fowl cholera virus; fowls and pigeons in a few tests have also been rendered somewhat resistant, though, at the present stage of the investigation, less so than rabbits.

---

*Contribution 208 from the Agricultural Experiment Station of the Rhode Island State College.

†Rhode Island Agr. Expt. Sta. Bul. 146, 1911; Centbl. Bakt., Abt. 1, Orig., 1911, 61, p. 323; Rhode Island Agr. Expt. Sta. Bul. 150, 1912; Centbl. Bakt., Abt. 1, Orig., 1913, 69, 271–311; and Rhode Island Agr. Expt. Sta. Bul. 157, 1914.

‡The M. L. D. of this culture was found to be from one to four organisms, inoculated subcutaneously.

In these cases, the test of immunity was usually inoculation with virulent Culture 48, a strain possessing maximum virulence. There exist in nature, one might believe, many different virulent strains of the fowl cholera bacterium and many that are non-virulent; the question is naturally raised whether Culture 52, which first proved effective in immunizing against Culture 48, would also create resistance against other virulent strains. During the past two years opportunity has been offered through the acquisition of new cultures, to put this matter to test. In addition, a continued study has been made of the immunizing ability of other non-virulent or slightly virulent cholera cultures obtained since the results reported in Bulletin 150.‡ It is therefore the aim of this paper to present data on both these subjects. Unless otherwise indicated the cultures were grown for 48 hours in beef or chicken broth at 37° C., and the inoculations made subcutaneously in the abdomen.

---

*See Rhode Island Expt. Sta. Bul. 157, 1914.

†Guinea-pigs are naturally immune to virulent fowl cholera cultures when inoculated subcutaneously.

‡At that time (1912), nine different cultures had been tested (16, 42, 45, 46, 47, 50, 51, 52, and 54). Of these, several were pathogenic for young or half-grown rabbits (45, 47), and all produced local abscesses upon inoculation, but none were fatal for adult rabbits. Of these nine, Culture 52 was the only one that conferred sufficient resistance to protect against large doses of virulent Culture 48. One possible exception to this was Culture 45 which, in one instance appears to have extended the fatal termination from 18 hours (which is about the average) to 6½ days; and Culture 54 which extended the period (one case only) to 3½ days. A repeated test of Culture 45, however. reported in this paper indicated no immunising power.

I. Protection Afforded by the Avirulent Cultures.

In this section are considered the nine avirulent or slightly virulent strains, 45, 63, 65, 66, 67, 69, 84, 96, 97; also the non-typical, cholera-like cultures 81, 82 and 85.† Culture 45 is re-tested.

Culture 45.—On July 2, 1914, a half-grown rabbit was inoculated with 0.1cc. of Culture 45. Infiltration, abscess and drainage followed. On July 8, this animal received 0.01cc. of culture 48. Death followed in about 14 hours, a control dying in the same time. No protection resulted from this inoculation with Culture 45.

Culture 63.—On July 2, 1914, a half-grown rabbit was inoculated with 0.1cc. of Culture 63. There was no reaction and on July 8, the same animal was re-inoculated with 0.01cc. of Culture 48. Death followed in about 38 hours, a control animal (1143) dying in about 14 hours. Apparently Culture 63 possesses practically no protective value against virulent Culture 48. The prolonging of the fatal termination in the treated rabbit is probably not significant. In fact, the absence of local reaction after the first inoculation suggested that too small an amount of culture had been injected. For this reason the test was repeated as follows:

On July 23, 1914, a half-grown rabbit was inoculated with 0.1cc. of Culture 63. Abscess and drainage followed. On July 31, this animal was inoculated with 0.01cc. of Culture 48. Death followed in 14 hours. Culture 63 furnished no resistance.

Culture 65.—On May 19, 1914, a three-fourths-grown rabbit (1096) was inoculated with 0.1cc. of Culture 65. Abscess and drainage followed. On July 2, 1914, this animal received 0.01cc. of Culture 48 and died in 16 hours; a control rabbit (1130) which received the same amount, dying in 15 hours. Apparently Culture 65 had no protective action against infection with Culture 48.

Culture 66.—On August 2, 1912, a rabbit (827) was inoculated with 1cc. of Culture 66. On the same date an adult fowl (827A) received the same amount deep in the pectoral muscles. The inoculations were repeated on August 15, the same amount of culture being used. On September 25, 1912, the fowl received 0.1cc. of virulent Culture 48 and experienced no ill effects. A control rabbit (869), receiving 0.001cc. subcutaneously, died in about 14 hours. Unfortunately the other rabbit was not inoculated at this time, but when it was inoculated December 17, 1913, with 0.1cc. of Culture 48, death followed in 13 hours. Apparently Culture 66 had no protective value.

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†See page 388.

Culture 67.—On August 16, 1912, an adult rabbit (860) was inoculated with 0.1cc. of Culture 67. On December 17, 1913, the same rabbit received 0.1cc. of Culture 48, and remained alive, while the control rabbit (1051) died in 12 hours. Apparently some degree of protection had been afforded by the earlier inoculation with Culture 67, and this resistance had endured through a period of one year and four months. Unfortunately, since Culture 67 was lost shortly after the above test was made, this result could not be confirmed.

Culture 69.—On May 13, 1914, an adult rabbit (1112) was inoculated with 1cc. of a 24-hour culture of Strain 69. On May 14, an infiltration had formed at the point of inoculation. On May 18, this had become necrotic and drained. On July 2, 0.01cc. of Culture 48 was injected, a control rabbit (1130) being inoculated with the same amount. The principal died in 19 hours, the control in 15.

The test was repeated as follows: On May 19, 1914, a three-fourths-grown rabbit (1097) was inoculated with 0.1cc. of Culture 69; abscess and drainage followed. On July 8, this animal received 0.01cc. of Culture 48, a control (1143) being inoculated with the same amount. The principal died in 16 hours, the control in 14. From these data it is clear that inoculation with Culture 69 afforded no protection against virulent Culture 48.

Culture 84.—This strain, when first tested showed weak virulence and is therefore listed among the virulent cultures considered in the second portion of this paper. Subsequently, however, even this slight virulence was lost, and for this reason it may also be regarded in the present section as a possible immunizing culture. But one test against Culture 48 was made. On July 2, 1914, rabbit 1136 was inoculated with 0.1cc. of Culture 84. Abscess and drainage followed on July 6. On July 13 the rabbit was tested with 0.01cc. of Culture 48 and died in about 16 hours. It thus appears that inoculation with Culture 84 furnished no resistance.*

Culture 96.—On June 11, 1914, an adult rabbit (1126) was inoculated subcutaneously with 0.1cc. of a bouillon culture of Strain 96. On June 17, there was a marked infiltration; an abscess formed and drainage took place June 26. On July 2, this animal was inoculated with 0.01cc. of Culture 48. Death followed in 15 hours, the control rabbit (1130) dying in the same time. Culture 96 thus appeared to have no protective value against virulent Culture 48.

Culture 96 was obtained in April, 1914, from Kral's Laboratory where it was maintained as the reported cause of a "Kanarienseuche." Upon morphological and cultural study, it appeared to show the typical features of the fowl cholera bacterium and is undoubtedly a member of this group.

Culture 97.—On June 11, 1914, an adult rabbit (1127) was inoculated subcutaneously with 0.1cc. of Culture 97. A slight swelling resulted, and in a short time followed the usual course of necrosis and drainage. On July 2, this rabbit was inoculated with 0.01cc. of Culture 48, a control animal (1130) receiving the same amount. Both animals died in 15 hours, demonstrating the absence of protective value in Culture 97.

Culture 97 was obtained in April, 1914, from Kral's Laboratory where it was maintained as *Bact. phasianicida* (Klein). As was the case with Culture 96, this bacterium resembled culturally the fowl cholera type, although in size it was slightly larger. In all probability it belongs to the fowl cholera group. Neither culture possessed virulence at the time of their acquisition.

Culture 81.—Among the known cholera cultures maintained in the laboratory collection, there was one which, though isolated from a cholera-like disease in poultry occurring in Rhode Island, departed widely from the fowl cholera type, especially with respect to its action on milk and on the fermentable sugars. This culture was, nevertheless tested for its immunizing power against virulent Culture 48. The data are as follows:

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*For other data on Culture 84, see page 397, second section of this paper.

On May 27, 1914, a half-grown rabbit (1120) was inoculated with 1cc. of Culture 81. Abscess and drainage followed. On July 8, this animal was inoculated with 0.01cc. of Culture 48. Death followed in about 14 hours, as in the control rabbit (1143). No protection had resulted from the earlier inoculation with Culture 81.

Culture 82.—On August 25, 1913, an adult rabbit (1029A) was inoculated with 0.1cc. of a 24-hour bouillon culture of Strain 82, supposed at the time to belong to the fowl cholera group. On August 29, there was an infiltration the size of a marble. On September 4, an abscess had formed and drained, and the wound had closed. On December 17, 1913, this animal was injected with 0.1cc. of a 24-hour bouillon culture of Strain 48. Death followed in 13 hours, as in the control (1051). No appreciable resistance had been conferred by inoculation with Culture 82.

Culture 82 was obtained in August, 1913, from Kral's Laboratory, where it was known as the "Würtzburg strain" of the fowl cholera bacterium. Virulence tests on a rabbit (1029A) and a pigeon (1089) were negative; the rabbit developed an abscess which drained and healed naturally. Subsequent to this, the cultural features of Culture 82 were submitted to a thorough study. In brief, it appeared that the Würzburg strain could not be classed with the fowl cholera type, and hence in any case, could scarcely be expected to develop immunity toward actual fowl cholera bacteria.

Culture 85.—On August 25, 1913, a rabbit (1032A) was inoculated with 0.1cc. of a 24-hour bouillon culture of Strain 85. On August 29, the infiltration was slight and no abscess had formed. No change had taken place on September 4. On September 14, nearly three weeks after inoculation, the animal died, presumably as a result of the inoculation. It thus appeared that Culture 85 possessed an intermediate virulence.

A further test was made as follows: On December 4, 1913, an adult fowl (1049), a pigeon (1050), two adult rabbits (1052), (1053), and one guinea pig (1054) were inoculated with Culture 85, in the following amounts, respectively: 1cc., 1cc., 2cc., 2cc., and 2cc. In rabbit 1052, no infiltration was produced; in rabbit 1053, a small hard infiltration was apparent on the fifth day after inoculation, but this was re-absorbed without becoming necrotic. All the animals mentioned above, together with one control rabbit (1051), were inoculated (birds, intramuscular; rabbits and guinea-pigs, subcutaneous) on December 17, 1913, with 0.01cc. of Culture 48. The fowl and the pigeon died in less than 24 hours. The two rabbits died in 14 hours, while the guinea-pig proved refractory.*

Culture 85 was obtained from Kral's laboratory in August, 1913, where it was known as the "Ficker strain" of the fowl cholera bacterium. Virulence tests were made as follows:

Rabbit — subcutaneous — 0.1cc. — lives.
Rabbit — subcutaneous — 2cc. — lives.
Rabbit — intravenous — 1cc. — lives.
Rabbit — intraperitoneal — 1cc. — lives.
Pigeon — intramuscular — 1cc. — lives.
Fowl — intramuscular — 1cc. — lives.
Fowl — by feeding — 10cc. — lives.

In rabbits the infiltrations were always small and frequently no abscess was formed.

Subsequent to these tests, which indicated that the culture possessed practically no virulence and no immunizing power, the cultural features were studied in detail, and indicated that Culture 85, as was the case with Culture 82, did not belong to the fowl cholera type. The fact, however, that in Kral's Laboratory Cultures 82 and 85 had been classed as fowl cholera organisms, suggests the existence in Europe of diseases clinically similar to fowl cholera, but characterized by a different etiology. Obviously, in these cases, no resistance against infection with Culture 48 could have been expected.

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*This does not necessarily imply that this animal had been rendered immune by the previous inoculation with Culture 85, since nearly all guinea-pigs are resistant to large doses of virulent cholera cultures when administered subcutaneously; intraperitoneal inoculations are fatal. In this case the subcutaneous inoculation was inadvertent.

Summarized statement regarding the immunizing value of the non-virulent strains.—During the past four years, seventeen strains of the fowl cholera bacterium have been tested for their immunizing power against virulent Culture 48. Of these avirulent cultures, nine were reported on in former publications* and the results need be only summarized here. The cultures mentioned were Strains 16, 42, 45, 46, 47, 50, 51, 52 and 54. Of these nine cultures, one only, Culture 52, possessed the ability regularly to produce immunity in the inoculated animals.

Of these later series of cultures, eight have been mentioned in the foregoing pages, viz.: Cultures 63, 65, 66, 67, 69, 84, 96 and 97; also the non-typical cultures of questionable position, 81, 82 and 85; also, Culture 45, mentioned in the former series, but re-tested at this time. Of these eleven new cultures, only one, Culture 67, showed protective value, and since this culture was lost, the circumstance cannot now be verified by a confirmatory test.

Up to the present time, therefore, a total of twenty avirulent strains (including the atypical and doubtful cultures, 81, 82 and 85), have been tested for their immunizing power. Of these, one only, Culture 52, has been fully demonstrated to possess this immunizing ability as a constant and never-varying characteristic. This strain may therefore be regarded as unique and in the following section will be considered the relation of this immunizing culture to certain strains, which, in contrast to the cultures mentioned in the present section, possessed a high degree of virulence for fowls, pigeons, rabbits and other laboratory animals.

II. Protection Afforded by Culture 52 Against Other Virulent Strains than Culture 48.

Under this head are considered infections with the twelve virulent Cultures 60, 61, 62, 64, 68, 70, 71, 72, 73, 83, 84 and 91. Culture 84 is considered also in the former section.

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*Rhode Island Agr. Expt. Station Bul. 150, 1912. Centbl. Bakt., Abt. 1, Orig., 1913, 69, 271–311.

Culture 60.—On January 22, 1912, an adult rabbit (799) received 1cc. of a suspension in broth of a 48-hour agar culture of Strain 52; abscess-formation and drainage followed. One week later, this rabbit received subcutaneously in the flank, 1cc. of a 2-day agar culture of Strain 48 and lived. On February 13, the animal received subcutaneously 0.1cc. of Culture 60 and lived, while two controls, (777, 800) which were infected in the same manner and with the same amount of Culture 60, died in 15 and 14 hours, respectively.

Obviously, from the result of this experiment one can conclude that the protection against Culture 60 may have resulted from the combined action of Cultures 52 and 48, rather than from the action of Culture 52 alone. No further light can be thrown on this point since Culture 60 was lost soon after the tests reported above were made.

Culture 61.—On September 29, 1911, two rabbits (752, 753) received each 0.1cc. of a bouillon culture of Strain 52. Abscess-formation and drainage resulted. On December 1, both rabbits were inoculated with 0.000,001cc. of Culture 48, and were immune, the control guinea-pig (698) inoculated intraperitoneally with 0.1cc. of Culture 48 dying in 39 hours.

Fifteen weeks after the inoculation with Culture 52, both the surviving rabbits, together with one control rabbit (756) were inoculated with 0.1cc. of a broth culture of Strain 61. The two immunized rabbits lived, while the control died in about 30 hours.

This experiment was repeated as follows: Two adult rabbits (681, 683) were inoculated on August 18, 1911, with 0.01cc. and 0.000,1cc. of Culture 52. In each, at the site of inoculation (abdomen), there developed an abscess which underwent natural drainage. On September 22, both rabbits, together with one control (685A) received 0.000,001cc. of Culture 48. The control died in two and one-half days; the other animals lived. On August 7, 1912, these animals were inouclated again with 0.01cc. of Culture 48; small infiltrations developed and they still proved immune.

On August 15, 1912, these two rabbits, together with one control (856) were inoculated with 1cc. of Culture 61. While both survived, the control died in 14 hours.

Obviously, in these experiments, one can assume that the resistance against infection with Culture 61, might have been determined by the combined action of Cultures 52 and 48, rather than by Culture 52 alone. This point has not further been tested since Strain 61 is no longer in the laboratory series of cultures.

Culture 62.—On February 25, 1914, an adult rabbit (1069) was inoculated with 0.1cc. of Strain 52. A typical abscess formed and underwent natural drainage. On April 15, 1914, this animal was inoculated with 0.1cc. of Culture 62. Death followed in 37 hours. A control pigeon inoculated in the breast muscle with the same amount, died in 27 hours. Other virulence tests were positive. In this instance it is apparent that the inoculation with Culture 52 on February 25 had practically no protective effect against Culture 62, a strain possessing fair virulence.

A further test was made as follows: On June 11, 1914, an adult rabbit (1125) nearly three years old, was inoculated with 0.1cc. of Culture 52. On June 17, the resulting infiltration had become necrotic and drainage took place on June 30. On July 2, this rabbit was infected with 0.1cc. of Culture 62, the material being inoculated several centimeters distant from the former lesion. A half-grown rabbit, serving as control (1137) was inoculated with the same amount. The principal lived, while the control died in 25 hours. In this case, protection appears to have resulted from inoculation with Culture 52, but in view of the difference between the results of the first and second tests, a third test was made as follows:

On July 2, 1914, a half-grown rabbit (1139) was inoculated subcutaneously with Culture 52 and typical abscess and drainage resulted. On July 8, this rabbit, together with one control (1146) the same size, age and weight, was inoculated with 0.1cc. of Culture 62. The principal died in about 24 hours, the control in 38 hours.

From the data on the three tests presented above, it appears that the results in the employment of Culture 52 as an immunizing agent against Culture 62 are variable. With the exception of Culture 83, this is the only instance in the period covered by the present study, in which the results are not clear-cut. In all other cases, Culture 52 immunizes perfectly or it confers no appreciable resistance. In the case of Culture 62, it may prove that further tests will settle the point one way or the other. At the present time, however, it seems that the protective power of Culture 52 alone against Culture 62 is negligible except in the case of vigorous well-matured animals.

The question now arises: Is the cumulative effect of an inoculation with, first, Culture 52, and later Culture 48, sufficient to prevent fatal infection with Culture 62. The following experiment bears upon this point.

On September 29, 1911, an adult rabbit (754) was inoculated with 0.1cc. of Culture 52. Another rabbit (755) was inoculated July 28, 1911, with 2cc. of Culture 52 in broth, heated at 44° C. for three hours. Both inoculations were followed by abscess-formation and drainage.

On December 1, 1912, the first rabbit (754) was inocluated with 0.000,001cc. of Culture 48, while the second rabbit received 0.000,000,001cc. Both lived, while the control guinea-pig (intraperitoneal) died in 39 hours.

On January 11, 1912 (15 weeks after inoculation with Culture 52 in the case of the first rabbit and 6 months later in the case of the second), both rabbits, together with one control (757), were inoculated with 0.1cc. of Culture 62. The first and second rabbits lived, while the control died in about 16 hours.

This test was repeated as follows: On July 17, 1911, two adult rabbits (588, 595) were inoculated one with 2cc. of Culture 52 in broth, the other with 0.1cc. The usual abscess-formation and drainage resulted. On August 4, both animals received 0.000,000,001cc. of Culture 48 and both lived. On August 7, 1912, both were inoculated with 0.01cc. of Culture 48 and lived.

On August 15, 1912, these same rabbits and a control (857) received 1cc. of Culture 62 in broth. The principals lived, while the control died in 14 hours.

In these cases, as in the instance of Culture 61, it is permissible to believe that the inoculation with Culture 48 in addition to the inoculation with Culture 52, favored the production of perfect immunity against infection with virulent Culture 62, toward which Culture 52 alone does not always exert a protective action.

Culture 64.—On July 17, 1911, an adult rabbit (628) was inoculated with 2cc. of Culture 52. On August 25, 1911, this animal received 2cc. of Culture 48, while a control rabbit (629) received 0.000,000,001cc. of Culture 48. Rabbit 628 lived, while the control died in about 14 hours.

On March 28, 1912, rabbit 628, together with a control rabbit and a control pigeon (591, 592) received 1cc. of Culture 64. The controls died in about 13 hours, while rabbit 628 lived. Here it is apparent that the combined effect of the inoculations of Cultures 52 and 48 was to afford protection against infection with Culture 64. Since this culture was lost, no opportunity was afforded to test it against Culture 52 alone.

Culture 68.*—On February 25, 1914, an adult rabbit (1070) was inoculated subcutaneously with 0.1cc. of Culture 52. On March 1, there was an abscess as large as a walnut; on March 3, this drained and soon healed. On June 11, the rabbit received subcutaneously 1cc. of Culture 68. There was no local reaction and the animal remained in good health. Unfortunately there was no control on this inoculation, although at the last previous inoculation of a pigeon with 0.1cc. of the same culture on May 14, 1914, the bird died in 13 hours, thus demonstrating high virulence. In order, however, more thoroughly to test the matter rabbit 1070 was re-inoculated on June 11, 1914, with 1cc. of Culture 68. There was no reaction; the animal remained in good health.

Culture 71.—On July 17, 1911, a young rabbit (627) was inoculated with 2cc. of Culture 52. On July 26, an abscess had formed, was incised and drained. Healing had taken place on August 25, 1911.

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*From Kral's Laboratory where it was known as the "Hanover Strain."

On this date the rabbit received 0.5cc. of Culture 48, and on August 2, 1912, 0.01cc. On November 7, 1912, 0.01cc. of Culture 71 was inoculated, a control (941A) receiving the same amount. The principal lived, while the control died in 18 hours. In this instance it is clear that the combined action of Cultures 52 and 48 furnished resistance against the virulent Culture 71. Whether Culture 52 alone would have given the same result cannot now be stated; Culture 71 was lost before other tests could be made. That the virulence of Culture 71 was great was shown by the following tests:

Rabbit, 1cc., subcutaneous, died in 18 hours.
Fowl, 0.01cc. intramuscular, died in 15 hours.

Culture 70.—On the same dates mentioned above with reference to the tests of Culture 71, other rabbits were tested with Culture 70. The rabbit (628) which had received both Culture 52 and 48 survived inoculation with Culture 70, while a control rabbit (942A) died in 14 hours. Owing to the loss of the culture it was not tested against Culture 52 alone. That it possessed high virulence, however, is shown by the following virulence tests:

Rabbit, 0.01cc. subcutaneous, died in 14 hours.
Fowl, 0.1cc. intramuscular, died in 15 hours.

Culture 72.—On June 30, 1911, a rabbit (943) was inoculated with 2 min. of Culture 52. On July 17, 1911, this animal received 0.000,000,000,001cc. of Culture 48 and lived. On November 7, 1911, 0.01cc. of Culture 72 was inoculated subcutaneously. The animal lived, while the control rabbit (943A) died in 60 hours. The combined action of Cultures 52 and 48 here also affords resistance, although the virulence of Culture 72 was not nearly as great as that of Cultures 70 and 71; this is indicated also by a virulence test in which a rabbit, inoculated subcutaneously with 1cc. died in 42 hours.

Culture 73.—On January 16, 1912, an adult rabbit (759) received subcutaneously 1cc. of Culture 52 on broth. An infiltration was formed and the consequent abscess drained as usual. On August 2, 1912, this rabbit received 0.01cc. of Culture 48. Infiltration and abscess-formation followed. On November 7, 1912, this animal received 0.01cc. of Culture 73 and lived, while the control rabbit (944A) died in 20 hours. In this case the inoculation with Culture 52, followed by inoculation with Culture 48, appears to have given perfect immunity. The protective value of Culture 52 alone was not tested because of the loss of Culture 73.

Culture 83.—On March 16, 1914, an adult rabbit (1075) was inoculated with 0.1cc. of a 48-hour broth culture of Strain 52. Abscess and drainage followed. On April 15, this rabbit received subcutaneously 0.1cc. of Culture 83. Death followed in 27 hours, whereas the control (1095) died in less than 24 hours. Apparently no protection had resulted from the earlier inoculation with Culture 52.

A second test was made as follows: On June 11, 1914, an adult rabbit (1123) received subcutaneously 0.1cc. of Culture 52. Abscess and drainage followed. On July 8, this animal was inoculated with 0.01cc. of Culture 83, a control rabbit (1135) receiving the same amount. The principal lived, while the control died in about 38 hours. From these data it is evident that Culture 52 possesses a certain amount of immunizing power against Culture 83, but that this power is somewhat unconstant.

These results may now be compared with a case in which a cumulative effect of inoculation with both Cultures 52 and 48 operates against infection with Strain 83.

On January 16, 1912, a rabbit (759) was inoculated with 1cc. of Culture 52. Abscess-formation and drainage followed. On August 2, 1912, the animal received 0.01cc. of Culture 48 and lived, while the control (824B) died in about 21 hours. On August 25, 1913, rabbit 759 was again inoculated, together with a control (1030A) with 0.1cc. of Culture 83. The principal lived, while the control died in 14 hours.

From these cases it is indicated that in one instance, inoculation with Culture 52 alone conferred no appreciable resistance against virulent Culture 83, while in the other instance resistance was produced by Culture 52 alone. Furthermore, that effective resistance is conferred by the inoculation of Culture 52 when followed after an appropriate interval with an inoculation with Culture 48.

Culture 83 possesses high virulence as indicated by the following tests:

Rabbit, 0.1cc., subcutaneous, died in 14 hours.
Pigeon 0.1cc., intramuscular, died in 54 hours.
Pigeon 0.1cc., intramuscular, died in 24 hours.

Culture 83 was obtained from Kral's Laboratory, where it was known as the "Kopenhagen Strain" of the fowl cholera bacterium. Cultural studies subsequently made demonstrated that it possessed the main features of the fowl cholera type, thus differing from the "Würzburg" and "Ficker" strains, which were probably not representatives of this group.

Culture 84.—On January 31, 1912, rabbit 783 was inoculated with 0.1cc. of Culture 52; abscess and drainage followed. On May 1, 1912, this animal was inoculated with 0.1cc. of Culture 48. Inoculation with 0.01cc. of Culture 48 was repeated on August 7, 1912. In both cases, the principals lived, while the control animals died in from 12 to 16 hours.

On August 25, 1912, rabbit 783 (1031) was inoculated, together with a control rabbit, with 0.1cc. of Culture 84. While 783 lived, the control died in about 84 hours.

The virulence of Culture 84 for pigeons and fowls was low as indicated both by the results presented above and by the following tests:

Fowl, 1cc., intramuscular, lives.
Pigeon, 0.1cc., intramuscular, lives.

This test was repeated as follows: On June 11, 1914, an adult rabbit (1124) was inoculated with 0.1cc. of Culture 52; abscess and drainage resulted. On July 2, this rabbit was inoculated with 0.1cc. of Culture 84. On July 3, a small swelling was apparent, but this was not followed by abscess-formation or drainage. The animal remained in good health. A control rabbit (1136) which received the same amount of Culture 84 showed a small infiltration on July 3, followed by abscess and drainage on July 6. Here it again appeared that

Culture 84 possessed almost no virulence. The control rabbit mentioned above was inoculated with Culture 48 on July 13, to ascertain whether the inoculation with Culture 84 had produced any resistance. Death followed in about 16 hours, thus demonstrating the lack of both virulence and protective power in Culture 84.

Culture 84 was obtained from Karl's Laboratory, where it was known as the "Halle Strain" of fowl cholera bacterium. Since in later tests, this culture was found to possess almost no virulence, it will be found listed also in the first section of this paper, among the avirulent strains.

Culture 91.—On March 16, 1914, a three-quarters-grown rabbit (1076) was inoculated subcutaneously with 0.1cc. of Culture 52. A typical abscess, with drainage, resulted. On April 15, 1914, this animal received 0.1cc. of Culture 91, subcutaneously; no ill effects were experienced. The control (pigeon, 1095) .died in less than 24 hours. In this instance it is apparent that the inoculation with Culture 52 alone was able to bring about complete resistance against Culture 91, thus suggesting that Culture 91 differs, either in degree of virulence or in some other biological feature, from Cultures 62 and 83, against which Culture 52 alone was found to produce immunity only irregularly. That as in the former cases, the inoculation of both Culture 52 and (later) Cultures 48 and 83, results in the production of resistance of a high order is shown by the following case.

On January 16, 1912, an adult rabbit (769) was inoculated with 1cc. of Culture 52 in broth. On August 2, 1912, the animal received 0.01cc of Culture 48 and lived, while the control (824B) died in about 21 hours. On August 25, 1913, the animal received 0.1cc. of Culture 83 and lived, while the control (1030A) died in 14 hours. On December 18, 1913, 0.1cc. of Culture 48 was injected and the animal lived, while the control died in 12 hours., On February 20, 1914, 1cc. of Culture 91 was injected. The rabbit lived, while the controls (rabbit, 1068; pigeon 1067) died in 12 hours.

From these tests it is apparent that inoculation with Cultures 52, 48 and 83 in series, gave perfect immunity against virulent Culture

91, although the degree was possibly no greater than that which would have been obtained from inoculation of Culture 52 alone, or from the combined action of Cultures 48 and 52.

Summarized statement regarding the protection afforded by Culture 52 against other virulent strains than Culture 48.—In the present section data are presented on attempts to produce resistance against 12 virulent strains of the fowl cholera organism, exclusive of Culture 48, the most virulent strain in the entire series. Against this strain successful immunization has already been reported.*†

Against five of the twelve virulent strains mentioned, immunization was attempted by the employment of Culture 52 alone. In three of the five cases, inoculation with Culture 52 conferred perfect resistance against the virulent strains (Cultures 68, 84 and 91). In the other two cases (Cultures 62 and 83), inoculation with Culture 52 alone did not produce resistance in all tests; the results were uncertain.

It appears, however, that in all cases in which the employment of Culture 52 alone failed to produce immunity or gave questionable results, viz.: against Cultures 62 and 83, a perfect resistance was produced by the employment of Cultures 52 and 48 inoculated successively in the sequence mentioned.

Furthermore, in all other cases in which it was not actually demonstrated that Culture 52 alone was protective against the virulent cultures (viz.: Cultures 60, 61, 64, 70, 71, 72 and 73) it was shown conclusively that the combined action of the two cultures (52 and 48) produced perfect immunity. These data may be summarized in Table 1.

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*See Rhode Island Agr. Expt. Sta. Bul. 155, 1913.

†See Centbl. Bakt., Abt. 1, Orig., 1913, 69, (4), 271.

TABLE I.—*Showing the protective value of Culture 52 alone, and of Culture 52 supplemented by Culture 48, against virulent strains of the fowl cholera bacterium.*

Virulent Cultures.	Culture 52 alone protects.	Culture 52 plus Culture 48 protects.
60	Not tested	+
61	"	+
62	(—) (+)*	+
64	Not tested	+
68	+	+
70	Not tested	+
71	"	+
72	"	+
73	"	+
83	(—) (+)†	+
84	+	+
91	+	+

*Result negative in two cases; positive in one case.
†Result negative in one case; positive in one case.

III. Discussion.

The data presented in the foregoing pages have a particular bearing upon two phases of active immunization,—one a general point, the other especially concerned with immunization in fowl cholera.

When the present investigation was begun it was not strongly anticipated that the experiments in active immunization would be productive of successful results. The idea involved was opposed to the chief trend of practically all previous experimental data with reference to fowl cholera; and, in fact, with reference to all diseases of the hæmorrhagic septicæmia group. It was thought that a few cultures might reveal a slight immunizing power. But it resulted that only one culture possessed any immunizing power whatever, while the immunizing power of that one culture was, so to speak, perfect. The results were so definite and so constant that it may now be said without exaggeration that there is no known bacterial disease in which active immunization can be obtained by so simple and so sure a method as in the present instance. A single subcutaneous injection of from 0.000,000,01 to 2.0cc. of living Culture 52 attains this end, within a period of seven days from the time of inoculation.

The question is now raised—What is the significance of this immunizing strain *par excellence*? Here, apparently is a unique culture of the fowl cholera bacterium,—one which cannot be differentiated morphologically, culturally or biochemically from sixteen other similar cultures which are also non-virulent, but fail to immunize; or from twelve other virulent cultures which invariably give fatal results on inoculation.

May we regard this as a hint that in other pathogenic bacterial species there exist, among the many avirulent strains, one or two, perhaps, that may be characterized as *immunizing cultures?* In pneumonia, for instance, there exists a disease in which the initial ineffectiveness of the natural body defenses against infection is almost as apparent as in acute hæmorrhagic septicæmia. One might inquire whether, among the multitude of avirulent cultures of the pneumococcus to be found widely scattered through the country, there exist strains, which by some form of inoculation and through some strictly local reaction, would call forth the immune response to more virulent cultural material. In this disease, and in some other communicable diseases of man and animals, might it not be worth while to make a systematic study of the reciprocal relations existing between various virulent and avirulent types?

In the second place, that data reported in this paper have an important bearing upon the formulation of practical measures for immunization against the hæmorrhagic septicæmias in general and against fowl cholera in particular. In an earlier paper it was shown that inoculation with Culture 52 protected rabbits against the single virulent Culture 48. In the present paper it is demonstrated further that Culture 52 protects against, not Culture 48 alone, but also at least three other virulent cholera cultures. But, what is perhaps more important, it is shown that in all cases in which Culture 52 alone fails to protect, the inoculation of Culture 52, followed by inoculation with Culture 48 yields perfect resistance. It suffices to say that in fowl cholera of rabbits, or rabbit septicæmia, these circumstances now afford a complete control of infection, so far as the employment of the thirteen virulent cultures maintained in the laboratory collection is concerned; and, it may be added, these include the most virulent strains obtainable from the laboratories of Europe and America. By the use of Culture 52 alone, or through the employment of Culture 52 supplemented by Culture 48, any rabbit may now be permanently protected against every strain of the fowl cholera bacterium yet obtained. With this point demonstrated, attention will now be directed toward ascertaining to what extent similar methods of active immunization may prove effective in controlling infection in birds. In this class of animals, the slightly greater natural resistance, as well as the marked difference in the type of tissue necrosis, may necessitate some modification in the original procedure.

IV. Summary.

The present paper presents the results of a study conducted to ascertain (1) the protective power of certain avirulent cultures of the fowl cholera organism against a highly virulent culture (Culture 48); (2) the extent and degree of protective power exercised by a certain immunizing culture (Culture 52) against twelve, heretofore untested virulent strains; (3) the protective power of combinations of cultures. The results, briefly stated, are as follows:

1. Among seventeen strains of the actual fowl cholera bacterium which have now been tested for their resistance-producing power toward a highly virulent culture, only one (Culture 52) was found which produced any resistance whatever; and this culture, upon subcutaneous inoculation, invariably gave perfect immunity against the most virulent culture in the laboratory collection (Culture 48).

2. This immunizing culture has now been tested (alone) against five other virulent strains, toward three of which it is also protective. In the other two cases, it is irregularly protective.

3. In the two instances (see above) in which Culture 52 alone failed to protect, or protected irregularly, complete protection was afforded by inoculation with Culture 52, followed after one week, or more, by inoculation with Culture 48.

4. In all cases in which Culture 52 alone was not tested against virulent cultures (seven), the inoculation with both Cultures 52 and 48 in the sequence and under the conditions stated, yielded complete immunity.

5. The results obtained in the investigation, thus far reported, are such as to afford, for the first time, complete control over infection in rabbits with probably any virulent strain of the fowl cholera bacterium. The method thus found successful for the active immunization of rabbits will now be employed, perhaps with modifications, in an attempt to produce a corresponding active immunity in birds.

THE COMPARATIVE EFFECT ON DIFFERENT KINDS OF PLANTS OF LIMING AN ACID SOIL

BULLETIN 160

Agricultural Experiment Station

OF THE

Rhode Island State College

KINGSTON, R. I., U. S. A., OCTOBER, 1914

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AGRICULTURAL EXPERIMENT STATION OF THE RHODE ISLAND STATE COLLEGE.

BULLETIN 160, OCTOBER, 1914.*

THE COMPARATIVE EFFECT ON DIFFERENT KINDS OF PLANTS OF LIMING AN ACID SOIL.

BURT L. HARTWELL AND S. C. DAMON.†

The data presented on the subject at this time will be limited almost entirely to those obtained from the permanent plats, 23, 25, 27, and 29, to which individual manurial applications were first made in 1893.

The previous publications‡ containing the detailed *field* records of the first eight years of the experiment are practically exhausted, and for that reason it seems desirable to attempt a concise presentation at this time, not only of the unpublished results, but also a summary of the published data which are now unavailable for general distribution.

APPLICATION OF MANURES.

Each annual addition of phosphorus and potassium has been the same for all four plats and applied uniformly; the variations from year to year depending upon what was believed to be the optimum requirements under the conditions.

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*Contribution 209 from the Agricultural Experiment Station of the Rhode Island State College.

†Until recently this investigation was in charge of the former director, H. J. Wheeler, who was assisted in the field work at different times chiefly by Messrs. Towar, Tucker, Tillinghast, Adams and Damon, assistants in agronomy.

‡Ann. Rpts. Agr. Expt. Sta., 6 (1893) 224-52; 7 (1894) 152-67: 8 (1895) 205-14; 9 (1896) 242-72; 10 (1897) 202-25; 11 (1898) 144-70; and 13 (1899-1900) 312-24. Bul. 46, Bul. 69, and Bul. 96.

The most usual annual application of phosphoric acid per acre during the first eight years was 120 pounds, supplied in dissolved boneblack, and since then from 60 to 75 pounds, supplied in acid phosphate. The annual application of potash, which was always supplied in muriate of potash, varied mainly from 75 to 100 pounds per acre. For a number of years prior to 1901, 400 pounds per acre of hydrated magnesium sulfate were added to each plat, with the object of guarding against any possible deficiency of magnesium: since then none has been added.

Although the amount of nitrogen has been the same for all four plats in any given year, plats 23 and 25 have always received it in sulfate of ammonia, whereas the source for 27 and 29 has always been nitrate of soda.

To plats 25 and 29, only, calcium oxid has been applied, always in slaked lime. Prior to 1902, the applications of the lime were made in 1893 and 1894.

Since the previous publication, the annual manurial applications and the crops have been as follows (accompanied by a summary of the same ingredients in the earlier years):

MANURIAL APPLICATIONS IN POUNDS PER ACRE.

YEAR.	CROP.	Nitrogen.	Phosphoric Acid.	Potash.	Calcium Oxid. (to plats 25 and 29).
1893–1900 total		358.5	912	1105	4750
1901	Soy Beans	18.	120	150	
1902	Oats	54.	60	100	800
1903	Hay	54.	75	100	......
1904	Miscellaneous	54.	75	100	......
1905	Leguminous	54.	75	100	......
1906	Cruciferous	54.	75	100	......
1907	Flowers	54.	75	100	......
1908	Flowers	40.	60	75	......
1909	Flowers	40.	60	75	......
1910	Barley, Millet	20.	60	75	......
1911	Corn	40.	75	60	......
1912	Potatoes	64.	120	150	800
1913	Rye, Rowen	40.	65	120	......
1914	Hay	36.	75	90	......
Total applications		980.5	1982	2500	6350
Average annual application		44.5	90	114	289

It will have been noticed that the experiment furnishes an opportunity to observe the effect of slaked lime upon plants in connection with both sulfate of ammonia and nitrate of soda as sources of nitrogen.

CHEMICAL WORK ON THE SOIL.

The determination of certain ash ingredients was made in the following crops grown on the four plats in 1894,* namely: white beans, orchard grass, blue lupin and tobacco. The ash of the tobacco from the unlimed plats was reddish brown and contained more iron than the light-colored ash of the tobacco from the limed plats.

In the Eighteenth Annual Report† of the station may be found the results of chemical work which had been done previous to its publication, with the soil from the four plats of the experiment. It included determinations of the total and free humus, lime requirements, etc. Some of the surface soil which had been kept in practically a moisture-free state since 1904 was analyzed recently under the same conditions as samples collected in September, 1912, so that the following comparisons are possible:

NITROGEN IN DRY SOIL FINER THAN 1 M.M.	Per Cent. 1904.	1912.
Unlimed sulfate of ammonia plat, 23	.223‡	.221
Limed sulfate of ammonia plat, 25	.231	.216
Unlimed nitrate of soda plat, 27	.231	.233
Limed nitrate of soda plat, 29	.217	.232

It may be seen that each unlimed soil had practically the same amount of nitrogen in the two years, and that in the limed soil the nitrogen had decreased where sulfate of ammonia had been added about the same as it had increased where nitrate of soda had been applied. This latter plat was the least acid of the four, in fact it was found to be neutral in 1904, although in 1912 it had become

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*Ann Rpt. 13 (1899-1900), 312-319.
†(1904-5), 242-252.
‡Determined in 1904.

somewhat acid. Nevertheless there was as much nitrogen in it in 1912, twenty years after the experiment was begun, as in the unlimed nitrate of soda plat, and this was in spite of the fact that in general the limed soil produced larger crops, which would be expected to remove more nitrogen.

Inasmuch as the extent of the effect of lime upon a given kind of plant depends upon the degree of acidity of the soil, it is important to bring before the reader at this time such determinations of the acidity as are available.

Samples of the surface soil, taken in May, 1904, and again, between the potato rows, in September, 1912, were found to require about the following amount of calcium oxid to neutralize the soil according to the Veitch method:

	Pounds of calcium oxid required per acre of soil.	
	1904.	1912.
Unlimed sulfate of ammonia plat, 23	4700	5500
Limed sulfate of ammonia plat, 25	1100	3200
Unlimed nitrate of soda plat, 27	2500	4200
Limed nitrate of soda plat, 29	0	2600

The last application of lime previous to 1904 was made in 1902 and was equivalent to 800 pounds of calcium oxid per acre. Previous to taking the samples in 1912, ten years had elapsed without any further application of lime. The result was that on the average about 1,800 pounds more of calcium oxid was required to neutralize the surface soil in 1912 than in 1904.

After the potatoes were dug in 1912, an application at the rate of 800 pounds of calcium oxid in slaked lime was made to plats 25 and 29 before seeding down with grass and rye.

In July, 1914, after the hay had been cut and while the plats were in sod, samples were again taken, this time to the depth of a foot instead of to the depth of the surface soil or about 7 inches, as previously. It was found that an acre-foot of the dry soil weighed about 3,100,000 pounds and contained 5.95 per cent. of material which did not pass through millimeter holes. The following determinations were made.

	Calcium oxid req. to neut. an acre-foot, lbs.	Loss on ignition of dry, fine soil, per cent.	Nitrogen, per cent. in dry, fine soil.
Unlimed sulfate of ammonia plat, 23...	7784	5.53	.157
Limed sulfate of ammonia plat, 25....	4607	4.57	.153
Unlimed nitrate of soda plat, 27......	4210	5.27	.154
Limed nitrate of soda plat, 29........	3069	4.90	.159

The cumulative relative effect of twenty-two annual applications of nitrogen in sulfate of ammonia and in nitrate of soda is shown in the amount of calcium oxid required according to the Veitch method to neutralize the soil in 1914. Where no lime had been applied, the plat which had received sulfate of ammonia required about 3,500 pounds of calcium oxid per acre more than the one which had received nitrate of soda; but where lime was applied, about 1,500 pounds more was required, or an average of about 70 pounds per year.

It may be seen that the loss on ignition was greater with the limed than with the unlimed soil; this was found to be the case also in 1904. Since there was no residual calcium carbonate in the limed soil, the assumption is probably warranted that most of the difference in the percentages is due to organic matter, a similar amount of loss in each case being attributable to changes other than combustion of organic matter.

Although the application of lime appears to have reduced the organic matter, there is no evidence that the nitrogen in the soil was thereby decreased.

This fact should be noticed by those who may have been unduly disturbed by the statement that slaked lime should be avoided because it "burns" out the soil nitrogen. It should be recalled in this connection that for a number of years there had been practically no growth of the legumes except on the limed plats; and, on the other hand, that more nitrogen had been removed from the soil in the crops taken from the limed plats, since, on the whole, these crops were larger.

BACTERIOLOGICAL WORK ON THE SOIL.

A test of the nitrifying power of the soil from the four plats was described in a former report* of this station from which the following is quoted: "Taken as a whole, the results may be said to indicate a somewhat greater activity of nitrous and nitric organisms from the limed than from the unlimed land."

During the summer of 1903, after receiving a master's degree from Brown University, Latham Clarke investigated the bacterial flora of the unlimed and limed sulfate of ammonia plats, 23 and 25, to ascertain if the types differed in soil having such different degrees of acidity, as shown by the previously recorded acidity determinations of 1904, which were made the following spring. The results with gelatine cultures were as follows:

		No. of apparently different bacterial types.	
	No. of plates made.	From plat 23 soil.	From plat 25 soil.
Aerobic cultures—			
Gelatin, 1.5% acid	36	10	2
" 0.2% acid	360	31	10
" 0.2% alkaline	36	6	14
Anaerobic cultures—			
Gelatin, 0.2% acid	24	6	6

In case of ærobic cultures in the *acid* gelatin there were more types from the more acid of the two soils, while in the *alkaline* gelatin there were more types from the less acid soil. This indicates that the bacterial flora is modified by the reaction of the soil in much the same way as the higher plants, for it is known that if a mixture of the latter were planted in soils of different reaction, the surviving individuals would be very different under the two conditions.

POT TEST ON THE NATURE OF THE BENEFIT FROM LIMING.

In November, 1906, soil was taken from plats 23 and 25, so that a pot experiment might be conducted in the greenhouse, by Frederick R.

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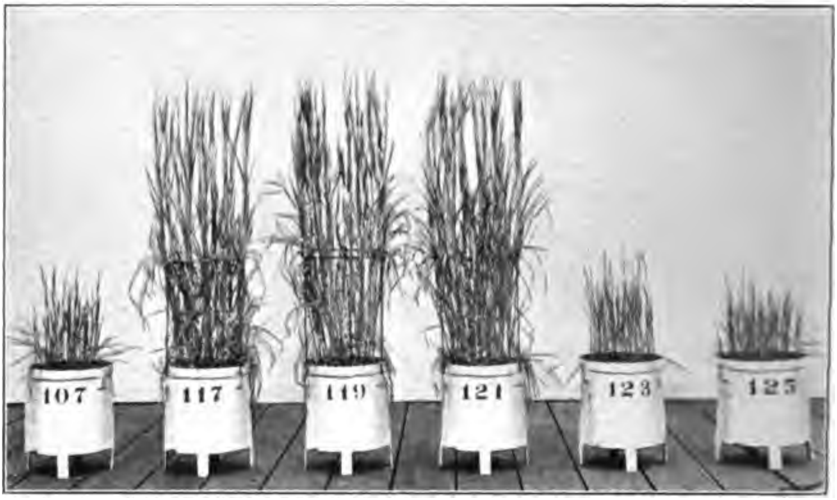
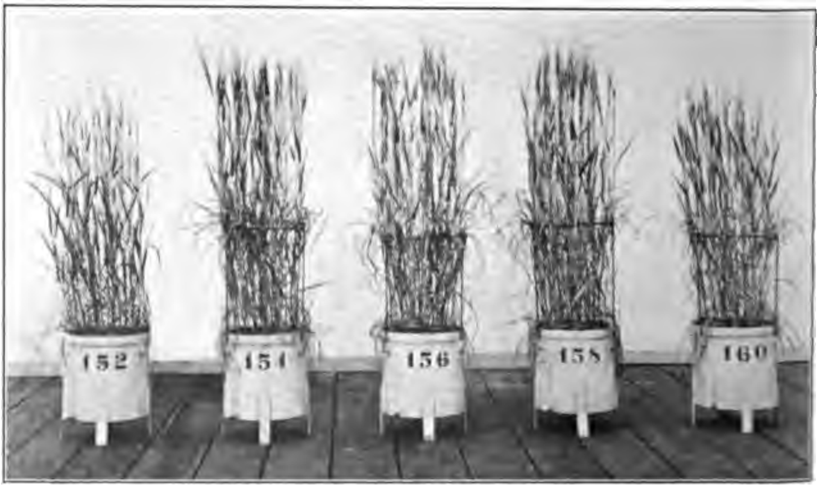
*Ann. Rpt. 13 (1899-1900) 319-324.



No Lime. Calcium Carbonate. Magnesium Carbonate. Calcium and Magnesium Carbonates. Calcium Sulfate. Magnesium Sulfate.

FIG. 1.—Barley grown in soil from the unlimed sulfate of ammonia plat.



No Lime. Calcium Carbonate. Magnesium Carbonate. Calcium and Magnesium Carbonates. Magnesium Sulfate.

FIG. 2.—Barley grown in soil from the unlimed nitrate of soda plat.

Pember, for the purpose of showing to what extent the beneficial effects of lime were due to its basicity instead of to its content of calcium; and also to ascertain if any benefit would result from changing the ratio of lime and magnesia, which ratio is considered by some to be of considerable importance.

To the soil in each Wagner pot, 8 x 8 inches, were added 1.39 grams of muriate of potash and 3.72 grams of acid phosphate, which was twice the rate of the field application of the same materials in 1906. Each pot of soil received the same amount of nitrogen, those from plat 23 in 1.78 grams of sulfate of ammonia, and those from plat 27 in 2.32 grams of nitrate of soda. This also was twice the field application of 1906.

Barley was planted in the pots on February 8, 1907, and harvested on May 22. The additional manurial applications made to certain pots, and the yields of barley cut from duplicate pots receiving the same were as follows:

SPECIAL MANURIAL ADDITIONS PER POT.	Grams of air-dry barley hay per pot. Plat 23 soil.	Grams of air-dry barley hay per pot. Plat 27 soil.
None	3.9	26.2
	3.9	29.4
14.35 grams c.p. calcium carbonate	54.2	43.9
	49.8	46.2
12.10 " c.p. magnesium carbonate	41.8	47.6
	40.8	46.1
7.18 " c.p. calcium carbonate and 6.05 " c.p. magnesium carbonate	48.7	46.7
	51.6	49.4
24.67 " c.p. hydrated calcium sulfate	5.3	......
	4.0	......
1.77 " c.p. hydrated magnesium sulfate	3.7	35.6
	4.2	36.3

The carbonates were added in chemically equivalent amounts whether applied separately or in combination. The hydrated calcium sulfate, gypsum, furnished the same amount of calcium oxid as the calcium carbonate. Maki and Tanaka* claim that for barley 14 parts of magnesium sulfate are agronomically equivalent to 100 parts of magnesite, natural magnesium carbonate, for supplying available magnesium, and this relation was adopted in connection with the applications of magnesium sulfate and carbonate in this experiment.

Practically no benefit resulted from the addition of calcium sulfate or of magnesium sulfate to the soil from plat 23. It was basic material that was needed, and it made no difference whether it was calcium carbonate or a mixture of this with magnesium carbonate. With the soil from plat 23 the magnesium carbonate alone, which is more soluble than calcium carbonate, seems to have been somewhat less beneficial. This was not true, however, in case of the soil from plat 27; in fact, there was a slight increase in crop also when magnesium was added in sulfate. (For illustration of one pot with each treatment see Figures 1 and 2.)

The experiment shows that the slaked lime used in the field was beneficial because of its basicity or alkalinity and not because it supplied calcium as a plant nutrient (it should be recalled that all plats received calcium sulfate in the annual applications of acidulated phosphates); and, furthermore, that probably no undesirable ratio of lime and magnesia had resulted from the manurial applications which had been made in the field.

THE INTERPRETATION OF THE TABULATED FIELD RESULTS.

In the following large table, the different kinds of plants which have been grown during the twenty-two years of the experiment on the four plats under consideration are arranged alphabetically under (1) flowers, (2) trees and small fruits, (3) grasses and clovers, and (4) miscellaneous crops, together with the results of their growth on each plat.

To obtain the clearest possible idea of the effect of liming upon a given kind of plant, the results from all four plats should be considered. Perhaps the most profitable comparison is that of the measurements on the nitrate of soda plats, 27 and 29. In general, the wider the ratio in the results from these two plats, the greater the benefit which may be expected from liming.

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*Bul. Col. Agr. Tokyo Imp. Univ., 7, (1906-8) 61.

A comparison of the results from the sulfate of ammonia plats, 23 and 25, would prove equally valuable were it not for the fact that this material tends to increase soil acidity, and its continued annual application has rendered the unlimed plat, 23, so acid that a great many kinds of plants have been unable to grow upon it, thus rendering impossible a comparison with the measurements from the corresponding limed plat. Those plants which can tolerate the very acid soil of plat 23 may be expected to receive but little benefit from the addition of lime to a moderately acid soil, and may even be injured by liming. The limed plat 25, which has received sulfate of ammonia has usually been less acid than the unlimed plat, 27, which has received nitrate of soda; and on this account a plant benefitted by liming would be expected to make a better growth on plat 25 than on plat 27. This may not be the case, however, in all instances because the sulfate of ammonia may have been inferior to the nitrate of soda as a source of nitrogen, in which case lime would not be the only factor tending to modify the relative growth on plats 25 and 27.

It will be understood readily that the degree of benefit from liming may depend upon many circumstances; and, therefore, that the relative effect of lime upon two different kinds of plants may be determined with much more certainty if a comparison is made of the results of a given year. It is partly on this account that the years when the tests of a given plant were made are given in the table. The detailed results for each year since 1900 are given, for they have not been published heretofore, but the earlier published results have usually been combined where possible.

The nearness to the time of liming obviously would influence the results, since those plants which preferred acid soil would be expected to be more tolerant of lime applied sometime previously than of a fresh application. On the other hand, those plants which were very intolerant of soil acidity, would probably make the greatest gain following a fresh application of lime.

Although liberal annual applications of nitrogen, phosphorus and potassium were made alike to the four plats, it was not proven that in all cases optimum amounts were present. If any of these ingredients were somewhat deficient in any case, the lime might then increase the available plant food, as well as decrease an injurious amount of soil acidity. It is of course also possible that the lime may have modified beneficially the physical conditions in some instances.

While recognizing the possibility that some of the influence from the liming may have been due to one or more of the causes just mentioned, it has been the general belief, based on considerable experimental work published elsewhere by this station, that most of the effects were due to a reduction in the amount of acidity in the soil, and that the marked difference in the effect of liming on different kinds of plants was associated with their comparative degree of tolerance of the conditions associated with that acidity.

Although it does not seem desirable to extend the limits of this bulletin in any great degree by a discussion of the reason for the marked differences exhibited by different kinds of plants in regard to soil reaction, it may interest the reader to know that this phase of the question is being studied at this station.

In the present instance the main object has been to present in a concise form, a considerable mass of experimental data concerning the effect of lime on different plants, under acid conditions which are believed to be similar to those existing in a large part of the country, for it is extremely important that the farmer becomes acquainted with these differences.

It may be determined eventually that acidity itself affects certain plants differently; or that there are substances in acid soils which are more toxic to certain plants than to others; or, as seems probable from certain results which have been obtained at this station, that there may be substances in the soil solution which protect certain plants more than others from the acidity. The reasons for the differences need not receive attention now, and for convenience reference will be made to acidity without further qualifications.

On account of the large number of different plants and the limited area devoted to the experiment, it has been impossible in most instances to devote much space to each kind of plant. The reader can often get an idea of the area involved, from the magnitude of the weights, and of course should place the most confidence in those results which were evidently secured from the larger areas. Each plat is 193.6 x 30 feet, two-fifteenths of an acre, but very often there was only a single row of a given kind of plant grown crosswise of the plats. Of course, when there are results of a number of years which furnish similar indications, confidence in the comparison should then increase.

In case of the miscellaneous crops as arranged in the table, an attempt has been made to state in the first column of the table the approximate relative degree of benefit from liming. Those crops which were benefited most are preceded by the figure 3, and those benefited in lesser degrees, by the figures 2 and 1 respectively. A large number of crops are tolerant of a moderate degree of acidity, such as may be said to have been present in plat 27, so that the addition of lime to such a soil (plat 29) resulted in only a small increase or decrease in yield. These crops are preceded by the figure 0. A few of the crops thrive much better without the addition of lime, and these have all been preceded in the table by "(—1)" without further classification.

It should be understood clearly that the object in attempting the above classification is to give to those who might not care to scrutinize the large number of weights recorded in the table an approximate idea of the need for liming. Like all classifications, there are uncertainties as to which of two contiguous groups shall contain certain individuals.

The effect of lime is different with different strains or varieties of a given kind of plant. For example, although beans in general are accompanied by a "0," this does not signify that certain kinds of beans might not be otherwise classified, but it does indicate that beans generally do not need liming, although if a discrimination is made as to a special kind of bean, it may be found that an application of lime is a matter of importance.

It is evident that in many cases the experimental data are too meager to allow a satisfactory classification: in a few instances, however, results from other experiments were taken into consideration in making the classification. On the other hand, sufficient data regarding certain kinds of plants have been secured at this station to enable classification into a larger number of groups than is attempted here. It was considered, however, that for practical purposes a larger number of groups was not required. When the reader sees that "3" accompanies a certain crop, he may know that inattention to lime requirements is liable to mean that the crop will not be satisfactory. Even if nothing is known regarding the requirements of the soil, it is much wiser to add lime as a preparation for such crops than to attempt to grow them without doing so. Probably an unsatisfactory growth of these crops is more often attributable to a lack of basic materials, such as lime, than to any other cause.

Of course, what has been said regarding the crops in group "3" is applicable in a lesser degree to the crops marked "2." The crops accompanied by "1" generally made a better growth on plat 29 than upon plat 27; but upon a soil somewhat less acid than that of plat 27, quite satisfactory growth might be secured without liming.

Under conditions existing on the average dairy farm it would probably be unnecessary in general to apply lime in preparation for those crops marked "0."

It will of course be understood that the figures used to represent the degree of benefit from liming are only relative, since the absolute amount of benefit for neutralizing purposes depends largely upon the amount of soil acidity and upon whether the lime is applied in such amounts and in such a way that the greatest possible beneficial effects are secured. Injudicious liming may result in a decreased crop under conditions where an application made properly would be beneficial. Especially where the acidity is either not large, or the crop is tolerant of the same, the effects of lime are quite variable, depending upon the form of lime and the method of application. Discussions regarding the relative merits of slaked lime and ground limestone of different grades of coarseness are quite futile unless the degree of acidity and kind of plant are taken into consideration.

TABLE SHOWING THE EFFECT OF LIMING ON THE GROWTH OF DIFFERENT KINDS OF PLANTS.

FLOWERS.

Flowers. (Most of them perennials. The figures show the average height in inches, unless otherwise stated. The weights given are in pounds.)

	Year.	Sulfate of Ammonia.		Nitrate of Soda.	
		Unlimed. Plat 23.	Limed. Plat 25.	Unlimed. Plat 27.	Limed. Plat 29.
Acanthus mollis, Bear's Breech	1907[1]	3.0	2.8	3.8	5.0
Achillea Ptarmica, Sneezewort	1907	13.5	20.0	16.3	19.0
	1908	12.0	25.0	21.0	24.0
Adenophora Potanini	1907[1]	1.3	2.1	2.0	2.3
Ageratum conyzoides,[2] Tom Thumb, wt	1904	11.5	54.5	56.5	66.9
	1908	5.0	8.0	8.0	8.0
Alyssum saxatile compactum	1907	3.5	4.5	5.0	4.5
	1908	.0	7.0	7.0	6.0
Alyssum maritimum,[2] Sweet Alyssum, wt	1904	.0	12.6	13.6	102.5
wt.	1906	.0	14.5	2.3	26.3
Aquilegia chrysantha, Columbine	1907	5.6	9.6	10.0	10.1
	1908	22.0	28.0	33.0	37.0
flabellata, nana alba	1907	3.2	4.4	4.1	5.3
	1908	3.5	5.5	7.0	9.0
vulgaris	1907	5.0	8.2	7.7	9.0
	1908	20.0	32.0	30.0	35.0
Asclepias Curassavica, Milkweed	1907[1]	10.2	15.0	14.5	19.5
Aster,[2] Comet Aster, wt	1898	2.4	3.8	3.1	4.2
	1908	4.0	5.0	6.0	6.0
Aubrietia deltoidea Graeca	1907[1]	1.3	1.8	1.0	1.5
Baptisia australis, Blue False Indigo	1907	7.0	6.2	7.4	6.0
	1908	10.0	12.0	16.0	17.0
Bocconia cordata, Plume Poppy	1907[1]	9.8	14.8	15.0	11.8
Japonica, Japanese Poppy	1908	44.0	66.0	59.0	57.0

---

[1] Winter killed.

[2] Annual.

FLOWERS—*Continued.*

	Year.	SULFATE OF AMMONIA.		NITRATE OF SODA.	
		Unlimed. Plat 23.	Limed. Plat 25.	Unlimed. Plat 27.	Limed. Plat 20.
Boltonia asteroides, False Chamomile	1907	32.3	43.0	41.6	40.8
	1908	38.0	57.0	56.0	59.0
Calandula officinalis,[2] Marigold	1908	14.0	14.0	14.0	14.0
Callirhöe involucrata, Poppy Mallow	1907	8.1	17.8	15.0	19.4
	1908	6.0	6.0	7.0	9.0
Canna sp., wt., including bulbs	1909	8.3	32.3	25.0	16.5
Cedronella cana	1907[1]	8.2	11.8	10.8	14.1
Chrysanthemum atrosanguineum	1907	3.5	8.2	9.1	8.1
	1908	17.0	22.0	25.0	24.0
Chrysanthemum coccineum	1907	3.5	6.6	7.9	8.3
	1908	9.0	16.0	14.0	15.0
prealtum aureum, Golden Feather	1907	3.0	4.4	3.7	5.7
	1908	8.0	13.0	14.5	13.0
Cochlearia officinalis,[2] Scurvy Grass	1906	.0	3.0	3.0	6.5
Coreopsis grandiflora, Tickseed	1907	9.5	12.2	11.8	13.5
	1908	29.0	35.0	32.0	35.0
lanceolata	1907	10.3	12.0	12.0	17.3
	1908	28.0	31.0	27.0	33.0
Delphinium Cashmerianum, Larkspur	1907	3.9	9.6	9.0	10.0
	1908	6.0	12.0	16.0	24.0
nudicaule	1907[1]	6.5	5.2	8.7	10.0
Desmodium tortuosum, Florida Beggar Weed	1905	1.0	2.0	2.2	2.4
wt.	1905	1.0	10.0	5.0	11.0
Dianthus barbatus, Sweet William	1907	3.6	8.0	7.2	9.0
	1908	10.0	21.0	23.0	23.0
Dianthus Caryophyllus, Carnation, wt	1897	.4	1.7	.7	1.3
Digitalis purpurea, Foxglove	1907	6.3	9.5	4.7	10.0
	1908	25.0	38.0	28.0	35.0
Eupatorium Fraseri, Snakeroot	1907	10.9	11.4	9.9	12.0
	1908	15.0	22.0	18.0	21.0

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[1] Winter killed.

[2] Annual.

FLOWERS—*Continued.*

	Year.	Sulfate of Ammonia.		Nitrate of Soda.	
		Unlimed. Plat 23.	Limed. Plat 25.	Unlimed. Plat 27.	Limed. Plat 29.
Gaillardia aristata, Aurora Flower	1907	3.3	5.0	6.0	10.7
	1908	12.0	17.0	18.0	24.0
Galega officinalis (See Fig. 3), Goat's Rue	1907	9.0	13.6	11.9	16.8
	1908	10.0	39.0	22.0	50.0
Geum Chiloense, Avens	1907	6.0	9.3	9.5	9.8
	1908	12.0	20.0	18.0	28.0
Gladiolus sp., No. flower spikes[3]	1896	29.0	40.0	36.0	38.0
Gypsophila paniculata, Baby's Breath	1907	8.1	13.4	11.9	8.7
	1908	5.0	10.0	20.0	26.0
Helianthus decapetalus multiflorus, Double Sunflower	1907	13.0	24.0	28.3	20.2
	1908	20.0	70.0	64.0	76.0
(mixed)	1907	18.0	23.0	25.0	25.0
	1908	28.0	38.0	43.0	40.0
Hesperis matronalis, Sweet Rocket	1907	2.0	3.5	2.0	5.2
	1908	7.0	7.0	8.0	9.0
Iberis amara coronaria, Candytuft, wt	1906	.2	9.8	6.0	9.0
Gibraltarica hybrida	1907	2.5	3.7	3.9	4.3
	1908	4.0	8.0	7.0	8.0
odorata, Fragrant Candytuft, wt	1906	.0	19.5	2.5	20.0
pectinata, wt	1906	.0	16.3	9.0	13.5
sempervirens, Evergreen Candytuft	1907	3.8	2.3	3.6	3.6
	1908	4.0	4.0	4.0	4.0
umbellata, wt	1906	.0	10.0	4.0	5.0
Impatiens Balsamina, Balsam, wt	1899	30.0	51.0	53.5	68.5
Lathyrus latifolius, Everlasting Pea	1905	2.0	4.2	4.0	4.4
wt.	1905	.0	5.6	2.5	4.0
	1907	9.0	15.1	16.4	21.3
	1908	12.0	40.0	40.0	44.0
odoratus,[2] Sweet Pea (No. Blooms)	1898	616	1433	1170	1848
(No. Blooms)	1899	780	3433	2777	3591
(America) Sweet Pea (No. Blooms)	1905	0	1518	1407	2351
(Blanche Burpee) Sweet Pea (No. Blooms)	1905	6	2628	2595	1691
Lobelia tennuoir	1907[1]	10.1	13.1	12.9	13.3

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[1] Winter killed.

[2] Annual.

[3] Inferior on unlimed plats.

FLOWERS—*Continued.*

	Year	SULFATE OF AMMONIA.		NITRATE OF SODA.	
		Unlimed. Plat 23.	Limed. Plat 25.	Unlimed. Plat 27.	Limed. Plat 20
Lunaria annua,[2] Honesty, wt	1906	1.5	15.0	11.0	12.5
Lychnis Chalcedonica, Jerusalem or Scarlet Lightning	1907	9.9	11.1	11.5	12.6
	1908	19.0	28.5	25.0	28.5
Haageana	1907	5.3	7.0	6.0	7.0
	1908	13.0	15.0	14.0	13.0
Malva Moschata, Musk Mallow	1907	4.0	11.2	10.2	19.2
	1908	18.0	16.0	16.0	14.0
Matthiola bicornis,[2] Stocks, wt	1906	.0	3.2	.8	14.4
sp.,[2] Dwarf Mixed Stocks, wt	1906	1.3	17.8	16.5	9.5
Mimulus cardinalis, Monkey Flower	1907	10.9	18.1	19.3	19.8
	1908	.0	3.0	8.0	12.0
Nicotiana sp., wt	1909	31.0	34.0	37.0	25.0
Papaver Rhoeas, Shirley Poppy, wt	1898–9	.0	12.3	4.8	20.0
No. Blooms	1898–9	0	1193	392	4271
Murselli, Mikado Poppy, No. Blooms	1900	0	22	3	160
somniferum, White Opium Poppy, No. seed capsules	1904	0	442	194	540
wt., seed capsules	1904	0	4.1	2.4	3.2
wt., plants	1904	0	15.3	12.0	15.0
Black Opium Poppy, No. seed capsules	1904	0	375	320	522
wt., seed capsules	1904	0	3.6	3.4	4.2
wt., plants	1904	0	21.3	23.5	23.0
Petunia sp.[2]	1908	7.0	9.0	9.0	10.0
Phlox Drummondii,[2] wt	1904	4.7	88.9	82.6	63.9
No. cymes	1904	374	8236	8487	7352
	1908	6.0	7.0	6.0	11.0
Platycodon grandiflorum, Japanese Bell Flower	1907	5.8	6.0	7.7	7.8
	1908	13.0	18.0	23.0	23.0
Polygonum Persicaria, Lady's Thumb	1907	16.1	30.9	30.3	40.9
	1908	12.0	20.0	22.0	24.0
Reseda odorata,[2] Mignonette, "Pierre Machet," wt	1904	0	77.4	66.6	141.8
No. spikes	1904	0	7148	6957	14062

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[2] Annual.

FLOWERS—*Concluded.*

	Year.	Sulfate of Ammonia.		Nitrate of Soda.	
		Unlimed. Plat 23.	Limed. Plat 25.	Unlimed. Plat 27.	Limed. Plat 29.
Salvia splendens,[2] Scarlet Sage	1908	6.0	6.0	6.0	6.0
Saponaria ocymoides, Soapwort	1907	4.3	8.5	8.5	9.0
	1908	5.0	9.0	6.0	8.0
Silene orientalis (See Fig. 4), Catchfly	1907	4.1	4.8	5.0	4.8
	1908	30.0	25.0	30.0	24.0
Stachys lanata, Woolly Woundwort	1907	4.2	6.3	6.3	6.2
	1908	9.0	20.0	12.0	24.0
Statice Tatarica, Sea Lavender	1907	1.6	1.8	1.5	2.3
	1908	7.0	9.0	10.0	12.0
Stokesia cyanea, Stokes' Aster	1907	3.5	5.0	4.7	4.2
	1908	7.0	11.0	9.0	14.0
Tropaeolum sp.,[2] Nasturtium, "Tom Thumb," wt. vines	1904	11.8	146.3	96.0	133.0
No. blooms	1904	798	3722	1822	4729
Viola sp., Pansy, wt. plants	1900	1.0	.8	.8	1.9
No. blooms	1900	976	1210	1437	2543
Zinnia sp., Youth and Old Age, wt. plants	1900	12.0	10.3	8.5	14.3
No. blooms	1900	191	176	190	469

[2] Annual.

TREES AND SMALL FRUITS.

TREES. (Most of the trees were set out in May, 1896, and removed in the fall of 1900. The figures refer to the average increase in diameter per tree, in inches, during the experiment.)

	SULFATE OF AMMONIA.		NITRATE OF SODA.	
	Unlimed. Plat 23.	Limed. Plat 25.	Unlimed. Plat 27.	Limed. Plat 29.
Apple, Baldwin	2.35	2.56	2.76	2.75
Golden Sweet	2.10	2.24	2.44	2.25
Birch, American White	2.19	1.94	2.19	2.21
Cherry, Black Tartarian	.09	.40	.53	.50
Early Richmond	1.23	1.60	1.54	1.65
Elm, American White	2.12	2.64	2.60	2.98
Linden, American	1.08	1.76	1.61	1.54
Maple, Sugar	1.08	1.02	.96	1.10
Peach, Early Crawford	2.66	3.06	3.02	2.75
Pear, Bartlett	1.93	1.10	1.28	1.35
Plum, Burbank Japanese	1.14	1.61	1.58	1.90
Quince, Orange (See Fig. 6)	.59	1.20	1.06	1.48
Spruce, Norway	1.54	1.09	1.69	1.39

TREES AND SMALL FRUITS.—*Concluded.*

SMALL FRUITS. (The figures refer to pounds of fruit unless otherwise stated.)

	Year.	Sulfate of Ammonia.		Nitrate of Soda.	
		Unlimed. Plat 23.	Limed. Plat 25.	Unlimed. Plat 27.	Limed. Plat 29.
Blackberry, Snyder	1898 1899 1900	30.19	52.10	30.17	17.52
Cranberry, American Bell (See Fig. 5)	1900	1.65	.25	1.50	.30
Currant, Prolific	1897 1899 1900	1.27	5.17	2.51	8.45
White Dutch	1897 1899 1900	6.51	13.87	8.07	17.80
Gooseberry, Smith's Improved	1897	.20	3.31	3.15	3.33
Grape, Concord, avg. of new growth per vine, yards.	1896 1897	7.49	28.05	30.58	30.37
total yield for two years	1899 1900	18.75	51.75	55.25	26.00
Delaware, avg. of new growth per vine, yards.	1896 1897	1.60	10.78	6.13	15.41
Raspberry, Blackcap	1899 1900	5.10	3.18	6.98	2.91
Cuthbert (red)	1899 1900	5.99	12.80	6.97	8.83
Strawberry, Chas. Downing	1897 1898	1.07	3.26	2.40	2.54
Haverland	1897 1898	2.32	4.54	3.83	4.21
Lady Rusk	1897 1898	1.85	3.40	4.07	4.59

GRASSES AND CLOVERS.

GRASSES. (The weights of the grasses for the individual years 1895, 1896 and 1897, having been published previously, only the total weight, usually for the three years, is now recorded in pounds.)

	SULFATE OF AMMONIA.		NITRATE OF SODA.	
	Unlimed. Plat 23.	Limed. Plat 25.	Unlimed. Plat 27.	Limed. Plat 29.
Awnless Brome, *Bromus inermis*	31.6	55.5	37.9	52.9
Kentucky Blue, *Poa pratensis*	23.7[1]	35.8	29.4[1]	37.3
Meadow Fox-tail, *Alopecurus pratensis*	21.8	41.0	36.3	47.0
Meadow Oat, *Avena elatior*	64.8	70.4	72.1	83.1
Meadow Soft, *Holcus lanatus*	103.2	122.5	96.9	111.3
Orchard, *Dactylis glomerata*	60.9[1]	87.2	78.2	96.8
Redtop, *Agrostis vulgaris*	75.3	71.7	64.0	71.3
Rhode Island Bent, *Agrostis canina*	67.5	61.1	53.6	62.0
Sheep's Fescue, *Festuca ovina*	23.5[1]	24.9	14.1	25.2
Sweet Vernal, *Anthroxanthum od. puelii*	9.5	15.4	16.7	17.2
Tall Fescue, *Festuca elatior*	61.0[1]	99.4	72.7[1]	93.2
Timothy, *Phleum pratense*	35.2[1]	54.9	45.7	54.5

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[1] Mostly other grasses or weeds, after the first year.

GRASSES AND CLOVERS—*Continued*.

CLOVERS. (The heights are recorded in inches and the weights in pounds.)

	Year.	SULFATE OF AMMONIA.		NITRATE OF SODA.	
		Unlimed. Plat 23.	Limed. Plat 25.	Unlimed. Plat 27	Limed. Plat 29.
Alfalfa, *Medicago sativa*, 2 cuttings, wt.	1895	.0	16.8	5.6	10.6
3 cuttings, wt.	1905	.2	30.0	18.0	35.5
ht.	1905	2.6	18.6	16.0	22.0
Alsike, *Trifolium hybridum*, wt.	1905	.2	35.5	37.9	37.5
ht.	1905	2.4	14.5	14.0	16.2
Berseem, Egyptian, *Trifolium Alexandrinum*, wt.	1905	.0	19.0	8.0	33.8
ht.	1905	.0	22.6	17.0	24.6
Bokhara, Sweet, *Melilotus alba*, wt.	1905	1.1	42.8	46.5	78.0
ht.	1905	2.7	10.1	10.5	16.9
Chinese, Milk Vetch, *Astragalus sinicus*, wt.	1905	.0	13.6	12.0	12.0
ht.	1905	.0	7.8	7.5	7.5
Crimson, *Trifolium incarnatum*, dried, wt.	1893	1.2	5.4	4.8	6.4
undried, wt.	1896	.5	25.5	17.0	27.2
wt.	1905	.6	54.5	51.5	57.0
ht.	1905	5.0	20.3	19.0	19.2
Hungarian, *Trifolium Pannonicum*, wt.	1905	.0	9.9	15.2	16.0
ht.	1905	.5	3.0	2.7	3.2
Japanese, *Lespedeza striata*, wt.	1905	1.6	7.3	5.6	6.0
ht.	1905	1.0	1.6	1.4	1.2
Red, **Mammoth**, *Trifolium medium*, wt.	1905	.9	45.4	51.6	45.6
ht.	1905	4.3	11.5	12.5	16.3
Medium, *Trifolium pratense*, wt.	1905	2.3	25.3	19.0	19.8
ht.	1905	7.8	19.0	18.0	21.5
Illinois, inoculated, wt.	1907	.0	11.0	17.0	17.0
uninoculated, wt.	1907	.0	7.8	14.0	11.0
2 crops, wt.	1908	.0	27.0	50.5	62.0
Illinois, wt.	1909	.0	35.0	105.0	154.0
Ufa Russia grown in Oregon, inoculated, wt.	1907	.0	6.0	7.0	8.0
uninoculated, wt.	1907	.0	6.8	9.0	9.0
wt.	1908	.0	18.0	32.0	27.0
wt.	1909	.0	67.0	128.0	137.0
Orel Russia, inoculated, wt.	1907	.0	6.8	5.5	7.0
uninoculated, wt.	1907	.0	5.5	5.3	6.0
wt.	1908	.0	6.5	14.0	18.0
wt.	1909	.0	140.0	163.0	180.0

GRASSES AND CLOVERS—*Concluded.*

CLOVERS—*Concluded.*

	Year.	SULFATE OF AMMONIA.		NITRATE OF SODA.	
		Unlimed. Plat 23.	Limed. Plat 25.	Unlimed. Plat 27.	Limed. Plat 29.
Red, Berne, Switzerland, inoculated, wt.	1907	.0	7.5	7.0	7.0
uninoculated, wt.	1907	.0	9.5	8.0	10.0
2 crops, wt.	1908	.0	35.0	34.0	28.0
wt.	1909	.0	85.0	99.0	89.0
England, inoculated, wt.	1907	.0	11.0	9.5	11.0
uninoculated, wt.	1907	.0	9.0	10.5	11.3
2 crops, wt.	1908	.0	42.5	45.0	43.5
wt.	1909	.0	78.0	77.0	77.0
White, *Trifolium repens*, wt.	1905	.2	40.6	46.3	39.5
ht.	1905	.8	10.0	10.0	12.0
Yellow Suckling, *Trifolium filiforme*, wt.	1905	.0	12.7	10.7	11.0
ht.	1905	.0	7.3	6.9	7.5
Yellow Trefoil, Black or Hop Medick, *Medicago lupulina*, wt.	1905	.0	26.2	18.8	28.7
ht.	1905	.0	10.0	6.8	9.3

MISCELLANEOUS CROPS.

(The measurements are recorded in inches, and the weights, given in pounds, refer to the part above ground unless otherwise stated.)

Degree of benefit from liming.		Year.	SULFATE OF AMMONIA.		NITRATE OF SODA.	
			Unlimed. Plat 23.	Limed. Plat 25.	Unlimed. Plat 27.	Limed. Plat 29.
3	ASPARAGUS,					
	Average height	1897	3.48	9.04	6.74	12.65
	Average height	1898	3.90	24.50	21.10	26.50
	Total yield for two years	1899 1900	.00	9.22	2.10	14.32
2	AUSTRALIAN SALT BUSH, undried	1899	.00	11.25	15.50	20.75
3	BARLEY,					
	air-dried	1893 1894 1895	.70	39.96	12.27	38.03
	undried	1896	1.90	56.40	21.85	50.40
	German, undried	1899	.20	.25	.10	.95
	Mansury, undried	1899	.65	6.50	2.25	7.50
	dried, grain ($\frac{1}{10}$ acre)	1910	.30	43.00	53.00	135.00
	straw $\frac{1}{10}$ acre)	1910	.30	287.00	302.00	376.00
0	BEANS,					
	Adzuki, White Podded, dried	1893 1894	7.50	11.02	12.04	10.31
	undried, wt.	1905	18.00	35.00	33.00	44.00
	ht.	1905	7.00	9.20	9.80	11.20
	Castor	1904	18.00	156.00	150.00	119.00
	Common White, dried	1893 1894	2.85	9.74	9.62	8.65
	Golden Wax	1894	.00	3.30	2.40	3.80
	unripe, unshelled, 48-ft. row	1904	1.00	23.10	22.94	23.50
	ripe, shelled, inoculated, 48-ft. row	1904	.12	5.12	5.12	6.26
	ripe, shelled, uninoculated, 48-ft. row	1904	.08	3.99	3.17	4.17
	vines and pods, inoculated, 48-ft. row	1904	.50	5.88	7.88	7.24
	vines and pods, uninoculated, 48-ft. row	1904	.21	5.21	5.17	5.83
	Horticultural Pole, pods and beans	1904	1.25	27.50	11.75	19.00
	Lima, undried (poor stand on plat 29)	1900	34.75	32.00	34.75	4.75
	Bush, unripe, unshelled, inoculated, 48-ft. row	1904	5.00	13.50	12.50	12.00
	Bush, unripe, unshelled, uninoculated, 48-ft. row	1904	8.33	26.37	21.33	16.17
	Bush, vines only, inoculated, 48-ft. row	1904	12.00	30.00	31.00	43.50
	Bush, vines only, uninoculated, 48-ft. row	1904	11.67	46.00	38.00	42.33
	Bush, wt.	1905	2.25	17.20	19.00	23.20
	ht.	1905	12.40	11.40	8.40	19.20

MISCELLANEOUS CROPS.—*Continued.*

Degree of benefit from liming.		Year.	Sulfate of Ammonia.		Nitrate of Soda.	
			Unlimed. Plat 23.	Limed. Plat 25.	Unlimed. Plat 27.	Limed. Plat 29.
0	BEANS—*Concluded.*					
	Marrowfat, white, shelled, wt.	1905	.06	2.30	1.80	2.40
	ht.	1905	5.00	28.00	13.00	25.60
	Red Valentine, unripe, unshelled, 48-ft. row.	1904	1.76	17.18	21.40	28.52
	ripe, shelled, inoculated, 48-ft. row	1904	.12	4.76	3.50	5.26
	ripe, shelled, uninoculated, 48-ft. row	1904	.25	3.56	2.94	4.69
	vines and pods, inoculated, 48-ft. row.	1904	.64	2.24	2.50	4.24
	vines and pods, uninoculated, 48-ft. row	1904	.25	2.19	2.06	4.31
	Scarlet Runner, wt.	1905	8.00	16.00	9.00	18.80
	ht.	1905	36.20	35.60	25.60	34.00
	Soy	1893 1894	14.18	69.88	65.81	64.50
	Medium Green, wt. of beans	1901	131.00	204.00	163.00	227.00
	Velvet, undried	1904	33.25	50.00	46.75	47.00
	wt.	1905	7.20	5.80	3.60	2.60
	ht.	1905	6.00	5.20	5.20	5.40
3	BEETS,					
	Mangel Wurzels, roots (See Fig. 10)	1893–6 1898–9	.85	377.00	154.25	590.25
	Sugar, roots	1893 1894	.00	48.50	6.00	69.50
	Table, Eclipse, roots	1893 1894 1895	.20	164.20	70.10	195.95
	Table, roots	1909	.00	1.75	21.50	99.00
2	BROCCOLI, Early White	1906	.00	35.00	16.00	33.50
1	BRUSSELS SPROUTS	1894	6.30	95.30	64.60	101.40
		1906	5.00	56.00	40.00	36.25
1	BUCKWHEAT,					
	dried	1893 1894	10.15	30.79	17.88	28.99
2	CABBAGE.					
	early	1893 1894	21.60	211.85	175.30	221.80
	late, heads	1893 1894 1895	.60	145.00	74.10	236.15
	Chinese	1906	1.40	69.40	32.00	62.40
	Flat Dutch, trimmed heads	1906	1.75	149.00	58.00	189.00
	Jersey Wakefield	1906	3.00	135.00	90.50	131.00
	trimmed heads	1906	.00	63.00	39.00	61.00
	Savoy Early Vienna	1906	5.75	90.00	47.50	90.00
	trimmed heads	1906	.25	33.00	11.50	36.00
	Stonehead, Red, trimmed heads	1906	2.50	66.00	30.25	66.50
		1909	.50	18.50	40.00	29.50

MISCELLANEOUS CROPS—*Continued*.

Degree of benefit from liming.		Year.	Sulfate of Ammonia.		Nitrate of Soda.	
			Unlimed. Plat 23.	Limed. Plat 25.	Unlimed. Plat 27.	Limed. Plat 29.
1	**Carrots,**					
	Danvers, roots	1894 1898 1899	18.10	136.05	131.10	117.15
	Improved Long Orange, roots	1894	.00	9.80	12.10	9.00
	Mastodon, roots	1893	.38	53.00	21.25	37.50
	Victoria, roots	1893	.00	32.50	17.50	31.25
	White Belgian, roots	1894	.00	13.40	16.40	19.40
	roots	1895 1896	.15	134.85	82.25	149.95
2	**Cauliflower,**					
		1894	.30	74.60	19.80	70.10
	Early Snowball	1906	1.75	27.00	24.75	42.25
3	**Celery**	1894 1895	.85	33.55	4.80	54.30
2	**Chard,**					
	Swiss, undried	1898	.00	19.75	21.25	48.00
0	**Chicory**, roots (See Fig. 7)	1898 1899	16.50	39.00	27.25	31.25
1	**Collards**, Georgia	1906	5.75	101.00	100.00	136.00
0	**Corn,**					
	Dent, undried	1893	2.50	15.00	9.25	9.88
	White Cap, undried	1893 1894 1895	5.21	63.04	61.83	48.30
	number of stalks (1/8 acre)	1911	1364	2263	2198	2336
	wt. ears, tip seed	1911	7	94	117	121
	wt. ears, middle seed	1911	2	117	101	85
	wt. ears, butt seed	1911	2	93	100	97
	wt. ears, small-ear seed	1911	3	98	94	91
	wt. ears, 12-row, ear seed	1911	27	105	120	123
	total weight of ears (1/8 acre)	1911	41	497	532	517
	wt. stover, tip seed	1911	14	72	104	112
	wt. stover, middle seed	1911	8	86	80	89
	wt. stover, butt seed	1911	8	85	80	92
	wt. stover, small-ear seed	1911	7	95	97	102
	wt. stover, 12-row ear seed	1911	34	120	127	140
	total weight stover (1/8 acre)	1911	77	458	488	535
	Pop, dried	1893 1895	7.75	69.06	63.68	75.74
	Sweet	1893 1894 1895	7.35	146.40	87.43	120.30

MISCELLANEOUS CROPS.—*Continued.*

Degree of benefit from liming.		Year.	Sulfate of Ammonia.		Nitrate of Soda.	
			Unlimed. Plat 23.	Limed. Plat 25.	Unlimed. Plat 27.	Limed. Plat 29.
0	**Cotton,**					
	Big Boll Upland	1904	.00	10.00	14.00	12.50
0	**Cowpea,**					
	undried	1893 1894	20.77	45.31	50.50	45.44
	Iron, air-dried, wt	1905	17.00	32.00	41.25	32.00
	ht.	1905	4.20	6.20	6.60	7.00
	Whippoorwill, undried	1899	73.00	61.00	69.50	55.50
0	**Cress,**					
	Broad-leaved winter	1906	3.00	12.00	12.75	12.00
	Fine curled, 2 crops	1904	.12	38.44	15.88	31.81
		1906	.75	11.50	12.50	14.50
1	**Cucumbers,**					
	fruit	1894	.70	36.10	28.90	87.30
	Improved White Spine, fruit	1904	.00	250.42	188.19	215.76
	vines	1904	.00	63.50	48.00	64.00
1	**Dandelion**	1894 1895 1896	.00	88.41	64.45	109.04
2	**Egg Plant,** fruit	1894	2.30	1.80	4.00	15.10
1	**Endive,**					
	Broad-leaved Batavian	1898	30.50	48.50	36.50	53.50
2	**Emmer, Speltz**	1904	.50	26.31	10.19	24.81
0	**Flax,** undried	1899	10.50	9.00	7.45	8.00
(—1)	**Furze,** wt	1905	3.00	2.75	4.00	1.00
	ht.	1905	3.20	3.20	3.00	2.60
3	**Gumbo**	1894	.00	20.00	2.10	23.80
	Hay, mixed ($\frac{1}{10}$ acre)	1903	435.00	612.00	475.00	700.00
	mixed ($\frac{1}{10}$ acre)	1914	410.00	545.00	435.00	725.00
2	**Hemp,** undried	1899	2.00	7.75	4.75	12.30
2	**Horse Radish,** roots	1906	.00	5.00	11.00	21.00
1	**Kale**					
	undried	1893 1894	25.46	214.56	157.36	234.96
	Dwarf Scotch Curled	1906	2.50	45.00	30.00	45.00

MISCELLANEOUS CROPS—*Continued.*

Degree of benefit from liming.		Year.	Sulfate of Ammonia.		Nitrate of Soda.	
			Unlimed. Plat 23.	Limed. Plat 25.	Unlimed. Plat 27.	Limed. Plat 29.
1	Kohl Rabi,					
	....	1894 1895 1899	4.80	76.30	49.90	76.95
	....	1906	1.00	71.00	42.75	69.00
3	Leek,					
	Carentan...........................	1898	.00	5.50	2.00	12.25
1	Lentils					
	wt.................................	1904	.06	6.44	5.38	8.94
	wt.................................	1905	.75	14.50	9.00	13.25
	ht.................................	1905	6.00	19.00	18.00	20.00
3	Lettuce,					
	....	1893 1894	.03	10.73	.73	16.13
	Butterhead, 2 crops..................	1904	.02	44.40	5.25	50.75
	Denver's Market......................	1897	.10	28.75	2.10	20.75
	Dwarf White Heart Cos, 2 crops.........	1904	.00	62.37	14.44	70.00
	Iceberg, 2 crops.....................	1904	.55	29.00	9.12	39.94
	....	1909	.00	1.25	2.75	3.00
0	Lupines,					
	Lupinus albus (white), ht...............	1905	4.40	8.00	8.60	8.00
	yield per 30 plants................	1905	.17	9.38	11.38	18.00
	Lupinus Hartwegii, yield per 50 plants....	1905	.48	5.36	3.84	5.88
	Lupinus Hartwegii albus, yield per 50 plants..........................	1905	.63	5.88	7.81	10.80
	Lupinus hirsutus (blue) dried, wt........	1893 1894 1895 1896	13.86	12.24	19.67	9.73
	Lupinus hirsutus (blue) ht..............	1905	13.00	17.00	19.00	19.60
	yield per 60 plants.................	1905	3.00	9.15	14.35	23.07
	Lupinus hirsutus foleis roseis, yield per 60 plants..........................	1905	7.50	4.46	4.55	10.91
	Lupinus luteus (yellow), ht..............	1905	7.00	5.00	5.60	7.40
	yield per 50 plants.................	1905	39.22	34.21	70.59	50.00
	Lupinus mutabilis, yield per 10 plants....	1905	3.64	6.00	7.50	5.19
	Lupinus mutabilis Cruckshankii, yield per 20 plants........................	1905	6.58	10.00	13.07	9.33
	Lupinus nanus, yield per 30 plants.......	1905	.38	4.29	5.00	3.75
	Lupinus polyphyllus, yield per 50 plants...	1905	.32	1.96	2.46	1.69
2	Martynia,					
	....	1894	1.00	22.50	17.80	50.60

MISCELLANEOUS CROPS.—*Continued.*

Degree of benefit from liming.		Year.	SULFATE OF AMMONIA.		NITRATE OF SODA.	
			Unlimed. Plat 23.	Limed. Plat 25.	Unlimed. Plat 27.	Limed. Plat 29.
0	MILLET,					
	....	1893 1894 1895	13.76	43.61	46.07	40.05
	Japanese, dried........................	1893	3.39	10.65	11.68	15.29
	($\frac{1}{10}$ acre)........................	1910	410.00	230.00	250.00	250.00
2	MUSKMELON,					
	fruit..................................	1894 1895 1897	.00	88.80	39.75	116.00
	Early Nutmeg, fruit..................	1898	15.25	106.80	79.50	126.75
	Netted Gem, fruit....................	1904	.00	61.00	4.75	80.94
	vines....................	1904	.00	46.75	3.33	48.50
2	MUSTARD,					
	White, undried.......................	1898	10.50	15.50	23.00	28.00
	Black, undried........................	1906	.25	13.75	5.60	27.00
	Chinese Broadleaf....................	1906	.50	28.50	16.25	33.25
1	OATS,					
	....	1893 1894 1895	19.96	27.80	21.94	24.08
	Pringle's Progress, undried..............	1899	10.25	13.25	12.00	15.25
	Black, from Bremen, air-dried...........	1899	2.80	2.45	2.45	3.50
	Legros, from Svalof, air-dried............	1899	1.25	1.65	1.15	1.45
	Golden Yellow, from N. W. Germany, air-dried..........................	1899	2.15	2.30	2.20	2.25
	air-dried ($\frac{1}{10}$ acre)	1902	533.00	652.50	554.00	723.00
3	ONIONS,					
	Barletta...............................	1895	.00	9.70	2.50	19.70
	Egyptian..............................	1895	.00	2.00	.05	1.55
	Red....................................	1894	.00	8.00	2.00	18.00
	Large Red Weathersfield...............	1899	.25	41.50	24.00	44.25
	Yellow................................	1894	.00	8.50	1.60	13.00
0	PARSLEY,					
	Fern-leaved, undried..................	1898	.30	2.10	2.00	2.15
3	PARSNIP,					
	roots..................................	1894	.00	31.30	4.80	33.50
(—1)	PEANUT.	1894	3.80	3.30	5.50	3.90

MISCELLANEOUS CROPS.—*Continued.*

Degree of benefit from liming.		Year.	SULFATE OF AMMONIA.		NITRATE OF SODA.	
			Unlimed. Plat 23.	Limed. Plat 25.	Unlimed. Plat 27.	Limed. Plat 29.
1	**PEAS,**					
	Canada Field, wt.	1905	1.00	23.50	18.00	30.50
	ht.	1905	6.00	60.00	51.60	65.00
	Flat, wt.	1905	.50	6.00	12.00	16.50
	ht.	1905	2.60	4.20	4.80	6.00
	Garden	1894	.10	13.70	8.00	14.20
	Gradus, unripe, unshelled, inoculated, 24-ft. row	1904	.06	7.28	5.44	6.50
	Gradus, unripe, unshelled, uninoculated, 24-ft. row	1904	.06	2.16	2.31	3.69
	vines, inoculated, 24-ft. row	1904	.38	6.88	4.91	6.69
	vines, uninoculated, 24-ft. row	1904	.06	3.19	2.56	4.69
	Garden, Gradus, wt.	1905	.50	9.05	8.90	15.70
	ht.	1905	6.00	16.40	16.00	27.40
	Granger	1893	.44	4.94	1.88	2.88
3	**PEPPER,**					
	fruit	1894	.10	4.50	2.30	6.30
0	**POTATO,**					
	Beauty of Hebron, tubers	1894	5.20	23.40	16.50	27.70
	Early Rose, tubers	1893 1894	7.55	21.80	22.86	23.74
	Norcross, $\frac{1}{20}$th acre basis,					
	R. I. seed, yield large, tubers	1912	....	252.00	500.00	476.00
	R. I. seed, yield small, tubers	1912	....	88.00	104.00	112.00
	Maine seed, yield large, tubers	1912	....	266.67	389.00	378.00
	Maine seed, yield small, tubers	1912	....	70.00	110.00	100.00
	Maine seed, yield total, tubers	1912	38.25	676.67	1103.00	1066.00
1	**PUMPKINS,**					
	fruit	1894	.00	31.50	87.20	48.50
	....	1895	.00	48.60	25.00	134.05
	....	1900	1.50	35.00	28.00	47.00
0	**RADISH,**					
	Scarlet turnip, roots	1894	.60	1.80	4.60	6.30
	Scarlet turnip, roots	1906	2.25	12.75	12.40	14.25
	French breakfast, roots	1894	.40	1.60	3.80	3.30
	Rat-tailed, roots	1906	.50	3.30	4.50	4.50
	Round Black Spanish, roots	1906	28.50	28.75	33.50	43.10
	Sakurajima, roots	1906	26.50	25.00	18.75	18.75
	White Strasburg[1], roots	1906	28.50	53.00	46.50	37.00
2	**RAPE**	1894	.00	97.80	58.00	114.40
1	**RHUBARB** (See Fig. 8)	1898 1899 1900	51.50	138.75	114.50	141.25

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[1] Many of the roots were decayed in the center.

MISCELLANEOUS CROPS—*Continued.*

Degree of benefit from liming.		Year.	Sulfate of Ammonia.		Nitrate of Soda.	
			Unlimed. Plat 23.	Limed. Plat 25.	Unlimed. Plat 27.	Limed. Plat 29.
3	**Rowen** (no clover on 23 and but little on 25, 1/10 acre)	1903	0.00	410.00	30.00	345.00
		1913	34.00	146.00	54.00	360.00
0	**Rye,**					
	undried	1893 1895 1896 1899	11.75	14.30	12.68	12.76
	air-dried	1894 1899	3.45	5.35	4.95	5.50
	air-dried, grain (1/10 acre)	1913	.00	177.50	166.00	174.00
	air-dried, straw (1/10 acre)	1913	.00	343.00	394.00	373.00
1	**Sainfoin,** wt.	1905	.00	5.50	6.40	6.75
	ht.	1905	.00	4.80	5.60	7.00
3	**Salsify** (oyster plant) roots	1894	.00	8.40	1.00	9.50
(—1)	**Scotch Broom,** wt.	1905	37.50	51.00	63.00	32.25
	ht.	1905	7.30	7.70	8.40	8.30
(—1)	**Serradella,**					
	undried	1895 1899	51.30	53.15	71.55	57.80
	undried	1905	34.20	57.00	67.50	47.50
2	**Sorghum,**					
	undried	1894	.00	58.40	23.60	70.50
	Amber Sugar Cane, air-dried	1893	.01	7.75	.29	3.06
	Broomcorn, Dwarf, undried	1898	4.25	80.00	70.00	80.00
	Kafir Corn, air-dried	1893	.02	7.75	1.29	4.38
	Jerusalem Corn, air-dried	1893	.00	1.34	.29	.78
(—1)	**Sorrel,**					
	undried	1894 1895	192.75	115.60	200.60	130.00
3	**Spinach,**					
	undried	1893 1894 1896	.00	14.48	.99	28.58
	New Zealand (See Fig. 9), undried	1897	1.00	37.75	10.75	52.50
1	**Spurry**	1904	8.75	41.00	25.50	39.75
1	**Squash,**					
	Hubbard, fruit	1904	.00	77.25	99.00	80.00
	vines	1904	5.00	157.50	135.00	165.00
	White Bush Scalloped, fruit	1900	32.00	49.25	44.00	66.50

MISCELLANEOUS CROPS.—*Concluded.*

Degree of benefit from liming.		Year.	SULFATE OF AMMONIA.		NITRATE OF SODA.	
			Unlimed. Plat 23.	Limed. Plat 25.	Unlimed. Plat 27.	Limed. Plat 29.
1	SUNFLOWER	1893 1894	4.05	124.18	99.49	127.80
1	TARES, Spring, ht	1905	7.00	51.00	39.00	48.00
3	TOBACCO	1894	1.80	38.30	9.50	43.00
0	TOMATO,					
	fruit	1893 1894	16.97	196.71	187.43	256.82
	Dwarf Champion, fruit	1904	4.67	38.74	37.87	33.43
	vines	1904	6.50	46.00	49.00	46.00
0	TURNIP,					
	Strap-leaf, Flat, roots	1894 1895 1899	42.00	216.55	173.00	215.80
	Ruta Baga, roots	1893 1894	26.25	248.30	194.25	308.50
	Golden Ball, roots	1906	6.80	40.00	43.60	30.60
	Purple Top, Strap-leaf, roots	1906	.75	15.75	15.75	18.00
	Ruta Baga, White-fleshed, roots	1906	1.40	18.00	28.80	32.40
	Sutton's Centenary, roots	1906	2.40	40.00	47.60	45.20
	Perfection Greentop, roots	1906	4.80	42.80	54.80	47.20
	Queen Swede, roots	1906	1.00	36.80	48.00	56.00
	White French, roots	1906	1.60	22.00	23.20	33.40
	Yellow Aberdeen, roots	1906	2.20	24.80	21.00	12.40
0	VETCH,					
	Kidney, wt	1905	.10	12.80	13.20	8.90
	ht.	1905	.00	7.00	7.00	7.00
	Sand, ht	1905	8.40	36.00	33.50	33.50
	spread of plants	1905	6.00	34.80	32.80	37.20
(—0)	WATERMELON,					
	fruit	1894 1895 1897	223.75	166.30	364.10	230.50
	Phinney's Early, fruit	1898	182.00	175.00	185.50	237.50
	Fordhook's Early, fruit	1904	61.00	175.87	223.00	140.00
	vines	1904	176.75	170.75	261.00	113.75
1	WHEAT,					
	Spring	1894 1895	.85	14.70	5.75	10.75
	Saskatchewan, undried	1899	.50	.70	.45	.70

DISCUSSION OF THE TABULATED DATA.

*Flowers.**

Most of the flowers included in the table are perennials which were started in the greenhouse; and, during June 4, 5 and 6, 1907, were transplanted to the field, each kind usually occupying a row crosswise of the four plats. The average height of the plants was ascertained on August 14. On November 29 the plats were covered with rye straw. Nevertheless, during the following winter a number of kinds were entirely winter-killed, as stated in the table; and, on June 10, 1908, annuals were set in the empty rows. The heights were measured on July 1.

Such perennials as lived were allowed an opportunity to occupy the land three growing seasons or until the fall of 1909, and notes were taken from time to time on the number and condition of the surviving plants. Since these notes, however, furnished indications regarding the effect of liming similar in general to those supplied by the heights recorded in the table, they need not be published here.

In October, 1909, the remaining plants were cut down, and in some cases the weights were taken, but inasmuch as the stand was usually different on the four plats, it seemed best not to extend the limits of the table by including these weights.

By reference to the table it may be seen that certain of the flowering plants were unable even to live on the very acid plat 23, so that only a zero could be recorded as a measurement; see, for example, sweet alyssum, candytuft, poppy and mignonette. In such cases there is usually a marked advantage in using lime also with nitrate of soda, (compare plats 27 and 29). Others, although able to live on the unlimed sulfate of ammonia plat, made a very unsatisfactory growth there, and were also much benefitted by liming even where nitrate of soda was used as the source of nitrogen; for example, foxglove, aurora flower, goat's rue (see Fig. 3), avens, balsam and nasturtiums.

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*Bailey's Cyclopedia of American Horticulture, The Macmillan Company, New York, 1900, has been followed in most cases in regard to Latin and common names.

Again, some of the flowers, although much benefitted by an application of lime with the sulfate of ammonia made practically the same growth with nitrate of soda whether lime was added or not; for example, sneezewort, ageratum, columbine, false chamomile, baby's breath and double sunflower.

Finally, there were a number of kinds of flowers which seemed to be quite tolerant of soil acidity, making a satisfactory growth, even on the very acid plat 23; conspicuous among these may be mentioned the blue false indigo, marigold, tickseed, evergreen, Japanese bell flower, *nicotiana*, scarlet sage and catchfly (see Fig 4).

Trees and Small Fruits.

Most of these were set out in 1896. They were young nursery plants and from five to ten of a given kind were set out crosswise in each of the four plats. In 1897, anumber of plants were replaced with new ones, the principal changes on each plat involving half of the currants and gooseberries, all of the Cuthbert raspberries, six of the Blackcap raspberries and the birches, and three of the maples. Five additional blackberry plants were set out on each plat. In 1898, the principal change involved the replacing of two of the pear trees on each plat by new ones, and the addition to each plat of five cherries (two varieties), five plums and six spruces.

The trees and shrubs were all removed in 1900. In the table, the effect of lime upon the trees is shown by their average increase in diameter during the time that they were in the experiment. This was determined by adding together the average increases for the first, second, etc., year of growth regardless of the calendar year in which the individual trees were set. Orange quince seems to have been markedly benefitted (see Fig. 6) followed by plum, linden and elm; whereas, Norway spruce, birch and peach, for example, seem to have been quite tolerant of acidity.

Among the small fruits, both varieties of currant were benefitted very much by liming. It is of interest to notice that the Cuthbert raspberry was benefitted, whereas the Blackcap produced much more on the unlimed than on the limed plats. In case of the plats receiving nitrate of soda, the blackberry also did better on the unlimed plat. The most pronounced case of injury from liming was illustrated by the cranberry (see Fig. 5).

Grasses and Clovers.

When comparing the weights of the different grasses given in the table, it should be recognized that in many cases, especially in case of the unlimed plats, with grasses whose growth was inhibited by an acid condition, a mixture of other grasses and weeds made up a large part of the weight, so that the benefit from liming such grasses was very much greater than would appear by the weights. For example, on the very acid soil of plat 23 scarcely any of the following grasses could live, namely: Kentucky blue, orchard, sheep's fescue, tall fescue, and timothy; while even on the unlimed nitrate of soda plat they were often partly replaced by other grasses. On the other hand redtop and Rhode Island bent grew well on the unlimed plats, even making their best growth on the very acid unlimed plat which received sulfate of ammonia. It has been noticed repeatedly at this station that when land is sown with a mixture of redtop and timothy, the proportion of the two which persists depends upon the degree of soil acidity.

It may be seen from the tables that scarcely any weight was secured from plat 23 in case of the clovers, but that some of them grew about equally well on the nitrate of soda plats, whether lime was added or not; notice, for example, mammoth, white and alsike. Other kinds, however, were much benefitted by the addition of lime in connection with nitrate of soda as a source of nitrogen; for example, alfalfa and sweet clover.

It appears as though the benefit from liming in the case of red clover depended somewhat upon the locality from which the seed came. In May, 1907, red clover seed from a number of different countries was obtained from the United States Department of Agriculture and planted under the same conditions, some of the seed in each case having been inoculated with the bacteria which inhabit the nodules of red clover and secure nitrogen from the air. Clover had been planted last on these plats four years previously, in 1903. The reader is simply referred to the table for the results of the inoculation since no general conclusions seem warranted and no observations were recorded regarding nodule formation. The red clovers having been winter-killed, a replanting with the same seed from the different localities was made in May, 1908, from which the results recorded for 1908 and 1909 were obtained.

Miscellaneous Crops.

On account of the great number of these crops, it is necessary to refer the reader to the table where the relative degree of benefit from liming the different crops is indicated by an integer as explained previously.

In addition to showing the effects of lime, the table includes certain other unpublished data secured incidentally with some of the miscellaneous crops, which will now be referred to in chronological order.

It may be seen by reference to the table that in 1904 certain kinds of beans were grown with and without inoculation by the bacterial culture which enables the bean to secure atmospheric nitrogen. Although there was an apparent benefit from inoculating Golden Wax and Red Valentine beans, the reverse was true with Lima beans. There was no special difference to note regarding the effect of lime whether the seed was or was not inoculated. Inasmuch as the annual application of nitrogen had been 54 pounds per acre for a few years preceding, it is not improbable that there was sufficient available nitrogen supplied in the fertilizers to render the beans independent of the supplementary source which may have been afforded by inoculation.

In 1905 the plats were planted with a large number of leguminous plants so that a comparison of these might be made under similar conditions so far as manurial applications and climate were concerned;

and in 1906 cruciferous plants were similarly compared. The comparative effect of lime upon the various members of these botanical families may be seen by reference to the table. It will be observed that the reference often made to the marked beneficial effect of lime for leguminous plants is applicable for only part of them, notable exceptions being cowpea, lupine, serradella and vetch.

Following the seasons of 1907, 8 and 9, when the plats were used mainly for the perennial flowering plants already considered, the entire area of the plats was sown to barley in 1910. This was able to make scarcely any growth on plat 23, although doing fairly well on the other three plats as shown in the table, the largest crop having been produced on the least acid plat, 29. As a second crop Japanese millet was sown on July 20, and it was soon seen that the best growth was on the most acid soil, that of plat 23. This was not because the reaction of the soil of this plat was the most suitable for millet; for, although quite tolerant of acidity, it is shown from results of other years that plat 23 was too acid for the best growth of millet. The millet was sown immediately after the barley was harvested and without any additional fertilizer. To secure some indication concerning the supply of available nitrogen, nitrate determinations were made in extracts from the soil of plat 29, and only 0.6 part of nitrate (NO_3) per million (p. p. m.) of extract was found. In the extract of the soil of plat 23, however, taken from sections where the millet was making slower growth than on other sections of the plat, there were 28 p. p. m. of nitrate, the amount increasing from the first to the fifth inch in depth. These poorer sections, however, were 50% more acid than other portions of plat 23, and it is interesting to find that nitrification could take place on such very acid soil. It seems probable then that the millet grew best on plat 23 because there was a larger amount of available nitrogen there, due to the fact that no barley could grow on this plat previously and thus consume the nitrogen.

An uneven growth of both barley and millet occurred on each of the individual plats due to some influence of the perennial flowering plants which had occupied rows crosswise the plats for a few years previously. *Achillea Ptarmica* (Sneezewort) caused the most marked depression in the growth of barley, whereas the growth was specially good following certain other of the flowering plants.

In the year 1911, the four plats were planted with White Cap flint corn, different rows having been planted, respectively, with kernels from the tip, middle and butt of the ears, with kernels from small ears and with kernels from twelve-row ears instead of from the usual eight-row ears. It may be seen by the table that there was the most stover from the twelve-row ears, and generally a little larger weight of ears. In case of each plat, only one-fortieth of an acre is represented by each kind of seed and further differences were not sufficient to warrant special mention on account of the small area involved.

In 1912 the plats were planted to potatoes and a comparison made incidentally between seed tubers from Maine and from Rhode Island. It is shown in the table that in this instance the crop was larger from the Rhode Island seed tubers, although in other experiments the reverse has been found more frequently to be true.

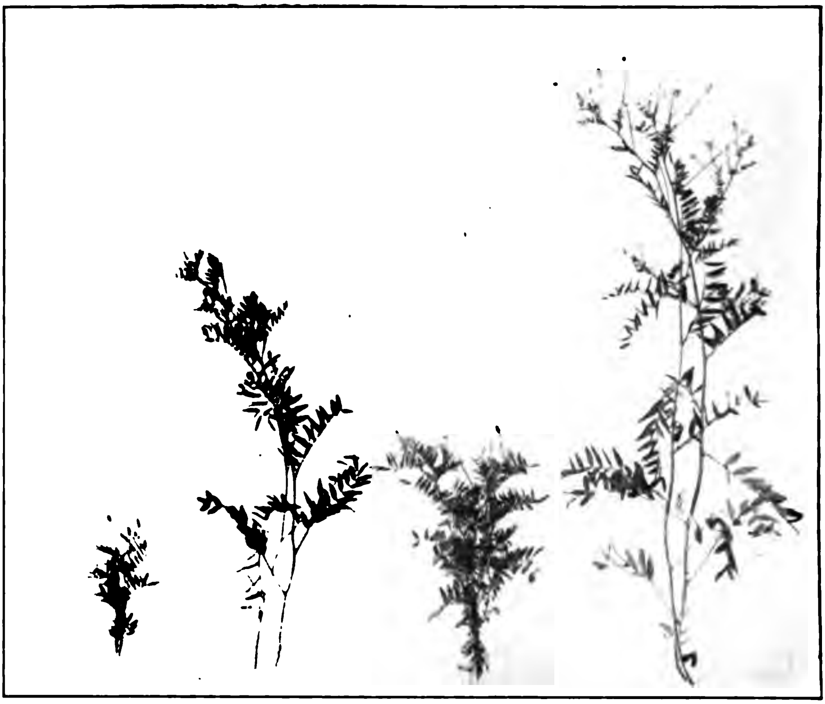
In the fall of 1912 the plats were seeded to a mixture of rye, timothy and redtop, and clover was sown in the following spring. Even though rye is quite tolerant of acidity, it could not grow on plat 23. It may be seen that the yields of both straw and grain, however, from the other three plats were quite similar. In the rowen following the rye there was no clover on plat 23 and but little on plat 27, whereas on the limed plats there was a good stand. In the following year, 1914, the grass on plat 23 was all redtop; on plat 27, nearly all redtop with only a little timothy; and on the limed plats 25 and 29, it was mostly timothy with some clover. Similar observations were made in 1903 when the plats were previously occupied entirely by the same mixture of grasses.

COMPARISON OF RESULTS WITH SULFATE OF AMMONIA AND NITRATE OF SODA.

Although the main factor influencing the growth of the crops on the four plats under consideration seems to be associated with the reaction of the soil, it is important to consider in so far as possible the agricultural value of the two sources of soluble nitrogen, since the market price per pound of nitrogen is now usually about the same in the two forms. It should of course be taken into account that their relative value as the entire sources of nitrogen as in the present instance may be different from their relative value in combination with other sources. The unlimed plat which has received sulfate of ammonia has been so infertile in most cases, due to its high acidity, that usually it will not now be given consideration. Plat 29, which has received both lime and nitrate of soda, although the least acid of the four plats, has usually been slightly acid, whereas the plat which has recieved nitrate of soda but no lime (27) would of course be more acid than plat 29. Plat 25 which has received sulfate of ammonia and also lime has usually ranked between these two in acidity, although the acidity determinations of 1914, previously given, show that it had then become the most acid of the three plats. Plants sensitive to acidity, therefore, such as those preceded in the table by figures 2 and 3, would from this standpoint be expected to produce yields decreasing in the following order of plats, namely: numbers 29, 25 and 27, and it may be found by reference to the table that this is usually the case.

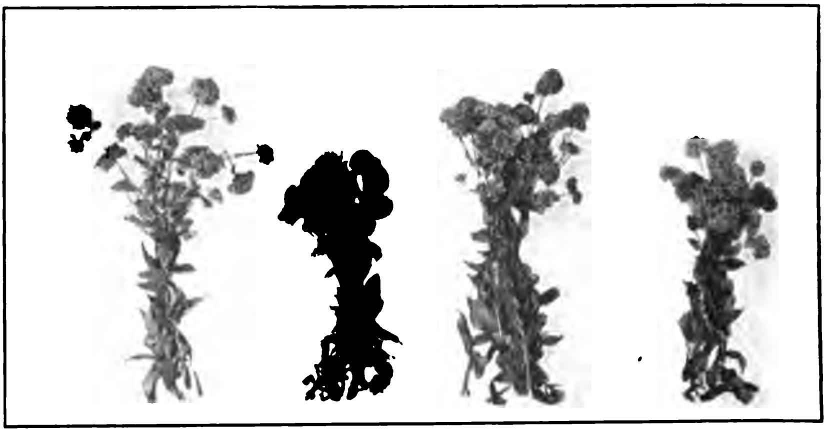
The yields of those plants which are less sensitive to acidity, grouped as "1" and "0," would not be expected to be all in this same order; and, as a matter of fact, about two-fifths of these yields as arranged in the table are larger from plat 25 than from plat 29, although the former plat is more acid. A similar comparison between the yields from plat 27 and 25 shows also that about two-fifths of the yields from plat 27 were greater than those from plat 25, even though here again the former plat was usually more acid. In one of these comparisons, then, a plat which received nitrate of soda excelled; and in the other, one which received sulfate of ammonia; the advantage in each case being with the plat which was usually less acid.

Although it is hardly probable that there was ever a deficiency of available potassium, it should be recalled that if such were the case, the sodium of the nitrate of soda might prove useful to certain plants,



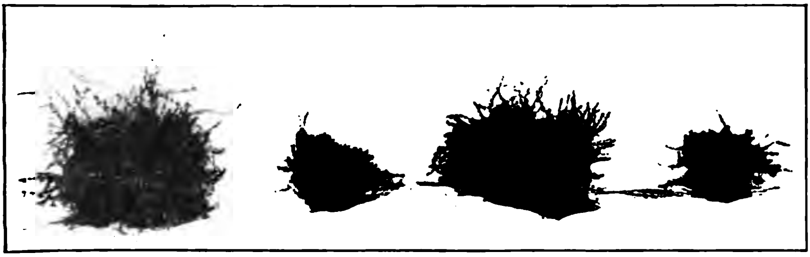
Unlimed. Limed. Unlimed. Limed.
Sulfate of Ammonia. Nitrate of Soda.

FIG. 3.—GOAT'S RUE.



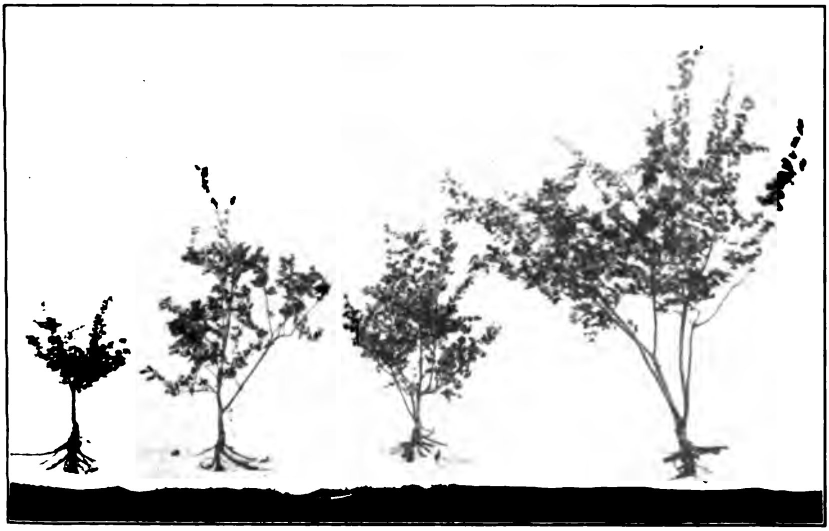
Unlimed. Limed. Unlimed. Limed.
Sulfate of Ammonia. Nitrate of Soda.

FIG. 4.—CATCHFLY.



Unlimed. Limed. Unlimed. Limed.
Sulfate of Ammonia. Nitrate of Soda.

FIG. 5.—CRANBERRY.



Unlimed. Limed. Unlimed. Limed.
Sulfate of Ammonia. Nitrate of Soda.

FIG. 6.—ORANGE QUINCE.

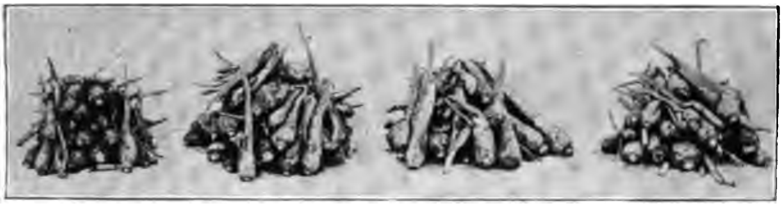


Fig. 7.—Chicory.

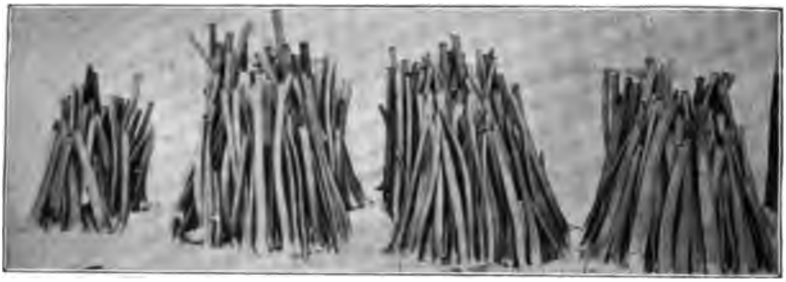


Fig. 8.—Rhubarb.

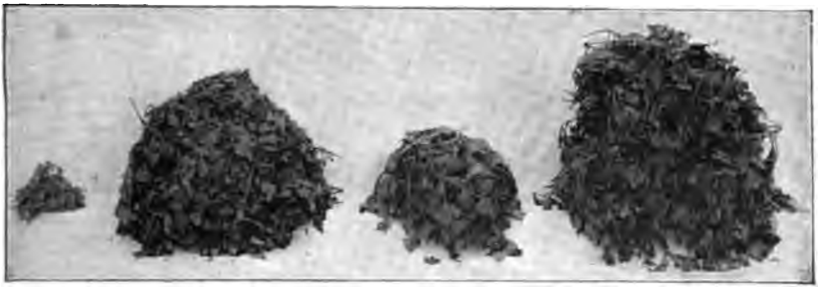


Fig. 9.—New Zealand Spinach.

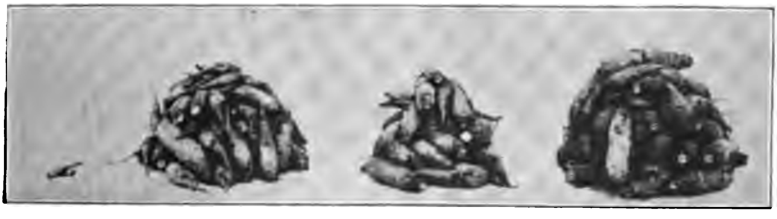


Fig. 10.—Mangel-Wurzels.

Unlimed. Limed. Unlimed. Limed.

Sulfate of Ammonia. Nitrate of Soda.

as has been shown repeatedly at this station. Any apparent superiority of nitrate of soda as a source of nitrogen, apart from its physiological alkaline effect, should be considered with this fact in mind.

It is impossible to compare satisfactorily the two salts only as sources of nitrogen unless in case of each, the reaction of the soil is made optimum for the growth of the particular kind of plant under consideration. To create such a condition there would usually be required the addition of a larger amount of lime in connection with sulfate of ammonia, because it is physiologically acid; and inasmuch as such larger amount has not thus far been applied in the present experiment, only those plants which prefer moderate soil acidity have usually grown better on the limed sulfate of ammonia plat than on the limed nitrate of soda plat, whereas the reverse is true of those plants which are sensitive to acidity. This indicates that in the present experiment the reaction of the soil may have had a more important influence on growth than the form of the nitrogen.

SUMMARY.

This bulletin treats of results secured during the last twenty-two years in connection with four plats equally and liberally manured so far as concerns the annual amounts of nitrogen, phosphorus and potassium. Two of the plats received their nitrogen in sulfate of ammonia, and the other two in nitrate of soda; to only one of each pair slaked lime was applied from time to time.

About 280 different varieties of plants have been grown upon the plats, divided about as follows: flowers, mostly perennials, 75; trees and small fruits, 25; grasses and clovers, 30; and miscellaneous crops, 150.

The results of the first eight years have been published, heretofore, but since the publications are practically exhausted, the results are summarized or referred to in this bulletin in connection with the later work.

Chemical, bacteriological and pot-culture work is involved as well as the securing of crop results in the field. To enable a concise presentation of the latter, they are arranged in tabular form with as few details as practicable.

The difference in the residual effect of sulfate of ammonia and nitrate of soda on the degree of soil acidity is shown to a marked extent; and as the same amount of lime was added with the two sources of nitrogen, the reaction resulting was liable not to be optimum for the growth of a given plant, in which case conclusions could not be drawn regarding the relative merits of the nitrogen in the two sources.

The approximate relative degree of benefit from liming, in case of the miscellaneous crops, is indicated by integers prefixed to the names of the crops alphabetically arranged in the table.

Plants are included representing all grades from those which are positively injured by an application of lime even to a very acid soil, to those which are unable even to live on an acid soil and are benefitted remarkably by lime.

PUBLICATIONS OF THE WORK OF THE AGRICULTURAL EXPERIMENT STATION OF THE RHODE ISLAND STATE COLLEGE, KINGSTON, R. I.

(Appendix to Bulletin 160.)

The funds at the disposal of this station, other than those provided for the fertilizer and feeding-stuff inspections, are available only for investigation and for the dissemination of the detailed results of its experiments. Because of this fact many of its publications are more specialized, and less adapted to the general reader, than may be the case with those from stations receiving state appropriations which may also be used for bulletins covering a subject in a popular way, regardless of the source and details of the information on which they are based.

In so far as funds are available for the purpose, the extension department of the college publishes brief popular bulletins, based upon experimental results secured at this or other stations.

Any individual publication (except those marked with a *) will be sent free upon request until the supply is exhausted. Those marked with a * are not available.

ANNUAL REPORTS.

*First (1888).

Establishment and organization.

*Second (1889).

Notes on the lines of work.
Reprints of Bulletins 1 to 4, inclusive.

*Third (1890).

Coöperative fertilizer experiments on corn.
Variety tests of fruits and potatoes and other vegetables.
Bordeaux mixture as a preventive of potato blight.

*Fourth (1891).

Coöperative fertilizer tests on corn.

*Fifth (1892).

Winter or spring application of ashes to meadows.
Coöperative fertilizer tests on corn.
Shrinkage in curing field corn.
Jensen hot-water treatment for oat smut.
Trials of different forms of phosphate.
Fertilizer experiments with oats.
Trials of lawn grasses, muskmelons and leguminous crops.
Potato scab.
Remedies for the rose-bug.
Cross-breeding of poultry.

*Sixth (1893).

Ill-effect of sulfate of ammonia, and the use of lime in overcoming the same.
Lime used in connection with organic nitrogen.
Coöperative field experiments.
Rotation of crops. Seed examination.
Applying liquid manure with hydrant water.
Experiments with turkeys and their diseases.

*Seventh (1894).

Soil tests with fertilizers and plants.
Growth of plants on unlimed and limed upland acid soil.
Value of soda in connection with potash.
Fungous parasites of the apple and pear.
Infectious disease of turkeys.

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*Not available for distribution.

*Eighth (1895).

Relative growth of sorrel and clover on limed and unlimed acid soil.
Growth of plants on limed and unlimed acid soil.
Value of soda in connection with potash.
Recognition of soil acidity, and its bearing on agricultural practice.
Ammonium thiocyanate in ammonium sulfate.
Soil tests with plants and fertilisers.
Different kinds of greenhouse piping.
Leguminous plants without and with nitrogen.
Three seasons cross-breeding of geese.

*Ninth (1896).

Oysters in Point Judith Pond.
Carnations, fairy ring disease, rust.
Value of soda in connection with potash.
Growth of plants on limed and unlimed acid soil.
Relative growth of different plants in a soil test.
Growth of barley on limed and unlimed acid soil.
On the general lack of lime in Rhode Island soils.
On the neutralising action of lime upon soil.
Trial of phosphates.
Northern vs. home-grown seed potatoes.
Army worm in Rhode Island.
Test of garden seeds.

*Tenth (1897).

Value of soda in connection with potash.
Effect of sulfur and sulfate of ammonia on potato scab.
Lettuce, cultivation, classification and description of varieties.
Potatoes, variety test, culture, in rotations.
Needs of certain Rhode Island soils.
Effect of lime upon plants.
Trial of phosphates.
The star-fish in Narragansett Bay.
Methods in planktology.
Geese, breeding and other experiments.

*Eleventh (1898).

Erroneous conclusions from plant soil-tests.
Nitrate of potash vs. muriate of potash and nitrate of soda.
Value of soda in connection with potash.
Growth of plants on limed and unlimed acid soil.
Lime requirements of Rhode Island soils.
Impurities in iron for nitrate determinations.
Treatment of oats to prevent smut.
Trial of "nitragin."
Notes on roup in fowls.
Pruning trees when planted.
Varieties of potatoes.

*Twelfth (1899).

Effect of slaked lime and other bases on humus and on humous nitrogen.
Effect of sulfur on potato scab.
Different clover and grass mixtures for seeding.
Effect of lime before and after seeding.
Nitrate of potash vs. muriate of potash and nitrate of soda.
Cherries. Lettuce. Rhubarb.
Pot experiments under glass.
Apple orchard. Blooming period of fruits.
Carnation stem-rot.
Principles of breeding.

*Thirteenth (to June 30, 1900).

Horticulture from an educational standpoint.
Regenerating an apple orchard.
Strawberry crosses. Plant selection.
Acidity of upland soils.
Roup. Poultry heredity.
Resistance to frost.
Carnation stem-rot.
The apple maggot.
Lettuce. Rhubarb.

*Fourteenth (to June 30, 1901).

Methods for chemical analysis of soils.
Apparatus for determining fat.
Field and pot soil-tests compared.
The forest, its influence and management.
Brooding incubator chicks.
Plant selection. Corn mixing.
San José scale. Apple maggot.
Fertilisers for bush-fruits.
Carnation stem-rot.
Methods of tree planting.
Carbon dioxid in incubators.
Goose cholera.
Notes on Rhode Island Reds.
Preservation of eggs. Trap nests.
Black Belgian hares.
Narrow, medium and wide rations for laying hens.

Fifteenth (to June 30, 1902).

Slate vs. boards for greenhouse benches.
Flowers for the home garden.
Effect of sugar and chemicals on color of flowers.
Strawberries, seedlings, fertiliser experiments.
Resistance of beans to frost. Corn selection.
Sand cherry and fruit rot.
Poisonous action of chlorids.
Five-year rotation, including clover.
Influence of the height of incubators on hatch.
Eggs and incubation.
"Blackhead" in turkeys.
Experiments with thoroughbred geese.

Sixteenth (to June 30, 1903).

Effect of sugar and chemicals on color of flowers.
Gasoline for squash enemies.
Spraying peach foliage.
Strawberry seedlings. Clover.
Blooming period of fruits.
Corn selection. Huckleberries. Ilex.
Durability of Posts.
Function of sodium in nitrate of soda.

Seventeenth (to June 30, 1904).

Tent covering for vegetables and strawberries.
Clover selection. Corn selection.
Apple maggot.
Magnesium as a manure.

Eighteenth (to June 30, 1905).

Bush-fruits. Corn selection.
Soil sterilisation. Apple maggot.
A market-garden rotation.
Tent covering for vegetables.
Strawberry seedlings.
Effect of extracting fertilisers at different times.
Methods of determining phosphoric acid.
Extraction in determining ash constituents.
Effect of liming upon soil constituents.
Ascertaining phosphoric acid deficiencies.
Cause of unproductivity in a soil.

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*Not available for distribution.

Nineteenth (to June 30, 1906).

Destroying charlock in grain fields.
Grafting-wax.
Lawn experiment.
A market-garden rotation.
A raspberry score-card.
Sterilized soil.
Tent covering for vegetables.
Concerning the functions of sodium salts.

Twentieth (to June 30, 1907).

Selection of clover, corn and strawberries.
Strawberry seedlings. Bush-fruits. Melons.
Apple maggot.
Frost resistant beans. Winter temperatures.
Lawn experiments.
Market-garden rotation.
Swedish turnip culture.
Effect of sodium on plants in solution cultures.
Relation of soil acidity to the effect of acid in solution cultures.

Twenty-first (to June 30, 1908).

Sodium as a partial substitute for potassium.
Relative toxicity of ferrous sulfate to barley and rye seedlings.
Mating experiments with bees.
The crow as a menace to poultry raising.
Methods of keeping pedigree records.

Twenty-second (to June 30, 1909).

Notes on the progress of the work.

Twenty-third (to June 30, 1910).

Notes on the progress of the work.

Twenty-fourth (to June 30, 1911).

Notes on the progress of the work.

Twenty-fifth (to June 30, 1912).

Notes on the progress of the work.

Subsequent notes on the progress of the experimental work since July 1, 1912, will be included with those on the other activities of the institution, in the Annual Report of the Board of Managers of the Rhode Island State College.

BULLETINS.

*1. Organization of the experiment station.
*2. The farm, historical, physical and geological description.
*3. Stock feeding.
*4. Bee keeping. Establishment of the apiary.
*5. Potatoes.
*6. Milk fever, or parturient apoplexy in cows.
*7. Catalogue of fruits. Report of apiarist.
*8. Soils and fertilizers.
*9. Experiments in apiculture.
*10. Mixed foods in cases of faulty appetite in horses and neat stock; including notice of patented and proprietary foods. Sore shoulders in horses.
*11. The state fertilizer law as it is and as it should be. Fertilizer analyses and comments.
*12. Further analyses of fertilizers with comments.
*13. Analyses of fertilizers and miscellaneous materials.
*14. Notes on the potato scab and Bordeaux mixture as a preventive of potato scab and of potato blight. Notes on transplanting onions.
*15. Treatment of loose smut of oats. Fungicides and insecticides. Black rot of the grape. Apple scab, coddling moth, canker worm and plum curculio.
*16. The new fertilizer law for Rhode Island. Selling price of fertilizer stock. Analyses.
*17. Analyses of commercial fertilizers.
*18. Fertilizer analyses. Caution regarding purchase of wood ashes.
*19. Fertilizer analyses with comments.
*20. Production of capons. Experiments in caponizing. Prices of capons, broilers, roasters and fowls in Boston and New York markets. When to make capons, the time to sell, and how to prepare for market. Caponizing tools, and how to perform the operation.
*21. Sea-weeds. Agricultural value and chemical composition.
*22. Strawberries. Cultivation and varieties.
*23. Fertilizers. Commercial and miscellaneous.
*24. Fertilizer analyses.
*25. Turkeys, experiments with; management of, by successful producers; wild turkey crosses, their desirability, and where they may be obtained.
*26. Fertilizers. Oats. Potato scab.
*27. Leaf blight of the pear. Raspberries; distribution of plants.
*28. Rhode Island soils. Fertilizers.
*29. Fertilizers.
*30. Fertilizers. Potato scab.
*31. Some special orchard treatment of the apple, pear, and quince.
*32. Fertilizer analyses.
*33. Fertilizers. Potatoes. Potato scab.
*34. Fertilizer analyses. Home-mixed fertilizers.
*35. Garden seeds.
*36. Potato culture. Hastening maturity.
*37. Apple culture.
*38. The bordeaux mixture.
*39. Fertilizer analyses.
*40. Fertilizers. Potato scab.
*41. Spinach.
*42. Fertilizers.
*43. Additional test of garden seeds.

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*Not available for distribution.

*44. Celery.
*45. The loganberry; from seed to fruitage.
*46. Lime and liming.
*47. Lime, nitrogen and soda.
*48. Fertiliser analyses.
*49. Liming in Rhode Island. Legumes.
*50. Utilisation of waste products and waste places. Part I. The nitrogen problem.
*51. Utilisation of waste products and waste places. Part II. The clam. Cultivation of tidal mud flats.
*52. Suggestions as to spraying.
*53. Practical bearing of some field and pot experiments conducted at this station.
*54. Commercial fertilisers.
*55. Forcing rhubarb.
*56. Fertiliser analyses.
*57. Quantities of nitrogen for grass.
*58. Financial gain from liming grass land.
*59. Fertiliser analyses.
*60. Fertiliser analyses.
*61. On the mortality of incubator chicks.
*62. Chemical methods for ascertaining the lime requirements of soils.
*63. Feeding-stuff inspection.
*64. Feeding. Feeding-stuffs.
*65. Fertiliser experiment with potatoes.
*66. Effect of lime upon grasses and weeds.
*67. Commercial fertilisers.
*68. Treatment of the sandy soils of Rhode Island.
*69. A study of plant adaptations.
*70. Commercial fertilisers.
*71. Top-dressing grass land.
*72. Special instruction in poultry culture.
*73. Commercial fertilisers.
*74. A rotation of crops.
*75. A four-year rotation of crops.
*76. A five-year rotation of crops.
77. Rations for milch cows.
78. Analyses of feeding-stuffs.
79. Fertiliser analyses.
*80. A modern dairy barn. Individuality of cows.
*81. Commercial fertilisers.
82. Grass experiments.
*83. Improving an orchard.
*84. Poultry feeding. Feeding-stuffs.
85. Fertiliser analyses.
*86. Goose septicæmia.
*87. Fowl typhoid.
88. The forests of Rhode Island.
89. Commercial fertilisers.
90. Further experiments in top-dressing grass-land.
91. Bush-fruits.
92. The soy bean.
93. Commercial fertilisers.
94. Commercial feeding-stuffs.
95. Coöperative experiments in top-dressing grass-land.
96. Influence of lime upon plant growth.
97. Commercial fertilisers.
98. Feeding-stuff analyses.
*99. A six-year rotation of crops.
*100. When to spray. Formulas, and notes on spraying.
101. Fertiliser analyses.
102. Fertiliser analyses.
*103. Grass experiments.
104. Plant peculiarities as shown by the influence of sodium salts.
105. Commercial feeding-stuffs.
106. Concerning the agricultural value of sodium salts.
107. Soil treatment in greenhouse culture.
*108. Fertiliser analyses.
109. A comparison of the results obtained by the method of cultures in paraffined wire pots with field results on the same soil.
110. Commercial fertilisers.
111. Potatoes.
112. Feeding-stuff analyses.
113. Continuous corn culture.
114. Test of nine phosphates with different plants.
115. Commercial fertilisers.
*116. Corn selection.
117. Fertiliser analyses.
118. Continued test of nine phosphates with different plants.
119. Commercial feeding-stuffs.
120. Soil tests in paraffined wire baskets compared with tests on farms.
121. A study of Rhode Island soil requirements by means of field tests.
122. Fertiliser analyses.
*123. The rearing and management of turkeys with special reference to the blackhead disease.
*124. Further experiments in connection with the blackhead disease.
125. Commercial fertilisers.
*126. Feeding experiments with chickens, cockerels, and turkeys.
127. Some recent feeding experiments. Feeding-stuff analyses.
128. A further study of soil treatment in greenhouse culture.
129. Experiments with feldspathic rock as a source of potassium.
*130. Fertiliser analyses.
131. Further soil tests in paraffined wire baskets.
*132. Fertiliser analyses.
*133. Weeds, their eradication and control.
134. Abstracts of feeding experiments. Feeding-stuff analyses.
*135. Further results in a rotation of potatoes, rye and clover.
136. Ropy milk in Rhode Island.
*137. Fertiliser analyses.
138. Fertiliser analyses.
139. Studies of the needs of Rhode Island soils.
140. Abstracts of feeding experiments. Feeding-stuff analyses.
*141. Blackhead in turkeys: A study in avian coccidiosis.
*142. The availability of certain unusual nitrogenous manures.
143. Nitrogen content and yield of crops as affected by different nitrogenous manures.
144. Fowl cholera and methods of combating it.
*145. Protein concentrates for winter chicks.
146. A biological study of eleven pathogenic organisms from cholera-like diseases in poultry.
147. The gain in nitrogen during a five-year pot experiment with different legumes.
148. Field experiments on individual farms.
149. Coöperative study of R. I. soil deficiencies.
150. Studies on fowl cholera: II. The role of an homologous culture of slight virulence in the production of active immunity in rabbits.
*151. Effect of cow dung on the availability of rock phosphate.

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*Not available for distribution.

152. Coöperative experiments in alfalfa culture.
153. The effect of sodium manuring on the composition of plants.
154. The percentage of total phosphorus in flat turnips as influenced by the amount available in soils.
155. Studies on inheritance in poultry: I. Constitution of the White Leghorn breed.
156. The availability of the nitrogen of cotton-seed meal and beef scrap for chicks.
157. Studies on fowl cholera: III. The inheritance in rabbits of immunity to infection with the bacterium of fowl cholera.
158. Studies on inheritance in pigeons: I. Hereditary relations of the principal colors.
159. Studies on fowl cholera: IV. The reciprocal relations of virulent and avirulent cultures in active immunisation.
160. The comparative effect on different kinds of plants of liming an acid soil.

INSPECTION BULLETINS.

Since July, 1910, these have been published in a separate series under the titles of Analyses of Commercial Fertilisers or Analyses of Commercial Feeding-stuffs, and designated by the month of issue. They contain only the analyses, and brief information to assist the consumer in understanding the relative merits of the different brands. Only a small number are printed in excess of the immediate needs, for they are mainly of temporary value.

CONTRIBUTIONS TO JOURNALS.

Only those published since 1909 are mentioned. A limited number of reprints of some of these are available to specialists.

Studies in avian coccidiosis: I. White diarrhea in chicks: II. Roup in fowls. Centbl. Bakt. (etc.), Abt. 1, Orig., 1909, 50 (3), 348–353.

*Note on the behavior of the domestic fowl. Amer. Nat., 1909, 43, pp. 669–676.

Notes on the parasitism of *Cylodites nudus* and *Hæmophysalis chordeilis*. Science, N. S., 1909, 30, p. 774.

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*Not available for distribution.

†Joint publication with the Laboratory of Genetics, Bussey Institution, Harvard University.

CONCERNING THE DISTRIBUTION OF BULLETINS.[*]

In the future the present mailing list of the station, and that supplied by the Office of Experiment Stations of the U. S. Department of Agriculture, will not be used in connection with the distribution of regular station bulletins.

On account of the experimental details and scientific discussions which these bulletins must contain to make the results of permanent value to investigators and to those charged with the duty of making direct applications of the material to the operations of the practical farmer, it seems inappropriate and uneconomical for the station to maintain a large mailing list, but rather to comply in the future with requests for individual bulletins, which are announced from time to time in the agricultural press or by the extension department of the Rhode Island State College.

If, however, there are individuals or institutions, who by their letter heads or explanations make it appear that all the bulletins in a given line would be likely to be appropriate to their needs, a limited number of names of such will, upon request, be placed on a new mailing list so that application for each individual bulletin will not be necessary. An applicant should submit his office instead of his name whenever by so doing frequent changes in the mailing list may be avoided; e. g. County Adviser, Blank, Mo.

The new mailing list will have two divisions in accordance with the two rather distinct lines of research now carried on, namely: (1) *Agronomy*, involving field, glasshouse and laboratory studies, the main subjects being rotations, the specific effect of different fertilizer chemicals and limes, the effect of crops on those which follow, the relative "feeding power" of different crops, nutrition, and soil acidity; and (2) *Animal Breeding and Pathology*, involving studies on

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[†] **Appendix to Bulletin 160.**

the communicable diseases of poultry with special reference to etiology and immunity; also on the manner of inheritance of characters, especially in poultry and rabbits. It will be necessary for the applicant to state in which line he is interested (1 or 2), if the request is to receive attention. New mailing lists also will be made to accomodate those who apply hereafter for either the fertilizer or feeding-stuff inspection bulletins.

A list of the past publications of the station bulletins precedes this announcement, and revised copies of the list will be furnished in the future upon request.

The extension department of the college is undertaking the more concise and popular presentation of farm matters; and requests for such information and bulletins should be made direct to the Extension Department, Rhode Island State College, Kingston, R. I., instead of to the Experiment Station.

Agricultural Experiment Station,

Kingston, R. I.

4

PURCHASE OF MISSING PUBLICATIONS.

Not having been able to secure, for binding, certain publications from the institutions which issued them, this station would be very glad to learn of any person who is willing to dispose of any of the following missing numbers, and of the price desired for each.

Missing from the publications of the Agricultural Experiment Stations:—

Alabama (Auburn) Bulletin 155. Circulars 4, 13. (Tuskegee Station) Bulletins 2, 14, 17, 22, 23. (Tuskegee Station) All Reports.

Arizona (Tucson) Reports 3, 4.

Arkansas (Fayetteville) Bulletins 3, 11.

California (Berkeley) Bulletins 1, 2, 3, 6, 50, 62, 66, 71. Circular 14 and Reports 1905-1912 inc.

Colorado (Fort Collins) Bulletin 180, Parts 1 and 3.

Connecticut (New Haven) Bulletins 1-17, 19-26, 29-32, 57, 61, 68.
(New Haven) Report 4 (1879).
(Storrs) Reports 24 (1911), 25 (1912).

Idaho (Moscow) Reports 1909-1912.

Indiana (Lafayette) Bulletins 1-4, 8, 9, 12. Regular Edition of Bulletins 143, 145 and Report 2.

Michigan (East Lansing) Special Bulletins 1, 3, 6. Report 1893.

Missouri (Columbia) Bulletins 2, 3.

New York (Geneva) Reports 1 (1882), 2 (1883), 3 (1884), 8 (1889).

North Carolina (West Raleigh) Bulletins 1-18, 22, 25, 27, 28, 33, 39, 48, 51, 55. Reports 1, 3, 33.

South Carolina (Clemson College) Bulletin 154, Reports 1 and 8 of Columbia.

South Dakota (Brookings) Report for 1899.

Washington (Pullman) Bulletins 12, 15, 54, 56-58.

Missing from the publications of the U. S. Department of Agriculture:—

Bureau of Animal Industry—Bulletin 6. Circulars 16, 82, 85, 88.

Bureau of Biological Survey—Bulletins 1-7 inc.

Bureau of Chemistry—Bulletins 1, 2, 3, 7, 8, 10, 11, 16, 38, 41, 161. Circulars 6, 11, 112.

Bureau of Entomology—Bulletins (old series) 1, 2, 5, 26, 30, and all after 32. Technical Bulletin 4.

Bureau of Forestry—Bulletin 23.

Bureau of Statistics—Bulletins 4, 6, 80, 86, 87, 92, 97, 98, and all after 103. Fiber Investigations Bulletins 2.

Division of Botany—Bulletin 4.

Farmer's Bulletin—No. 327.

Office of Experiment Stations—Bulletin 253. Circulars 2-6 inc., 9, 10, 13-16 inc., 21, 24, 26, 48.

U. S. Dept. of Agr., Office of Secretary—Circulars 1, 2, 5, 16, 18, 39, 42, and all after 45.

U. S. Dept. of Agr.—Reports 1-57 inc., 91, and all after 98.

U. S. Dept. of Agr.—Index to Year Books previous to 1901.

Address:

Agricultural Experiment Station,
Kingston, R. I.

Studies on Inheritance in Poultry: II. The Factor for Black Pigmentation in the White Leghorn Breed.

BULLETIN 161

Agricultural Experiment Station

OF THE

Rhode Island State College

KINGSTON, R. I., U. S. A., DECEMBER, 1914

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AGRICULTURAL EXPERIMENT STATION OF THE RHODE ISLAND STATE COLLEGE.

BULLETIN 161, DECEMBER, 1914.

STUDIES ON INHERITANCE IN POULTRY: II. THE FACTOR FOR BLACK PIGMENTATION IN THE WHITE LEGHORN BREED.*

PHILIP B. HADLEY.

It has been shown by Goodale† and by the present writer,‡ and has sometimes been noticed by observant poultrymen, that crosses between the White Leghorn and the White Plymouth Rock breeds of fowl may give rise in F_2 to barred, or otherwise dark colored individuals. This circumstance naturally brings up a question regarding the origin of the black pigmentation necessary for bringing out the barred pattern in F_2. It has been assumed that the White Plymouth Rock fowl does not harbor the factor for black pigmentation, since, whenever black is added to the White Plymouth Rock, as by crossing with a black breed, the barred pattern is manifested. Therefore it has appeared probable that the factor for black pigmentation was present in the White Leghorn. Strong evidence in favor of this view was presented by the present writer in an earlier contribution.‡ But Bateson and Punnett§ have described an instance in which two types of white fowl, when mated together, produced progeny, all of which were dark colored, thus suggesting that each type contained one of the two factors whose combination was necessary in order that pigmentation might result. The observation made by Bateson and Punnett naturally suggests the possibility that the White Leghorn does not carry the factor, or factors, for black pigmentation, but contributes only one (X) of two necessary factors, while the White Plymouth Rock contributes the other (Y). This point can be tested by properly devised experimental matings and it is the aim of the present contribution to report the results of an experiment in cross-breeding which has a direct bearing upon it.

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*Contribution 211 from the Agricultural Experiment Station of the Rhode Island State College.

†GOODALE, H. D., Experiments with poultry, Proc. Soc. Expt. Biol. and Med., 1910, (7), 178-9.

‡Studies on inheritance in poultry: I. The constitution of the White Leghorn breed, Rhode Island Agr. Expt. Sta., Bul. 155, pp. 151-216, 1913.

§BATESON, WM., and PUNNETT, R. C., Report to the Evolution Committee of the Royal Society, IV, pp. 28, 29, Publ., Harrison and Sons, London, 1908.

The stock used was pure White Leghorn and White Plymouth Rock, line-bred for many generations. The crosses were made in only one direction, White Leghorn ♂ × White Plymouth Rock ♀♀. The majority of the birds were raised to five months of age, and some were kept until they were mature.

Before presenting the experimental results, a word should be said regarding the zygotic constitution of the White Leghorn, since this point has an important bearing upon the interpretation of any results obtained. This breed is characterized by the so-called "dominant white," as contrasted with the "recessive white" present in the majority of other white breeds, including the White Plymouth Rock, White Minorca, and White Silky, for example. In crosses between the White Leghorn and such black fowl as Black Hamburg, Black Minorca, Black Spanish and Black Java, the F_1 birds are invariably white, frequently showing splashes or flecks of black, and less often a barred or partly barred feather. In F_2 the typical Mendelian ratio appears, 3 white : 1 dark. The dark birds comprise both black and barred individuals in the ratio 1 : 3, as stated in an earlier paper.*

One is naturally led to inquire,—What is the nature of the dominant white character in the White Leghorn? The Leghorn white is due to the absence of color, but it is illogical to say that the absence of pigment is dominant over its presence. We are forced to conclude that the White Leghorn and other breeds, such as the White Dorking, characterized by the D–white, must contain some pigment-destroying or pigment-neutralizing character which prevents the manifestation of black. The exact nature of this character is unknown, but it may be referred to merely as an inhibiting factor (I), for which the White Leghorn appears to be homozygous. It may be similar to the inhibiting factors (W_1, W_2, W_3, etc.) which Cole* finds present in pigeons.

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*HADLEY, P. B., The presence of the barred plumage-pattern in the White Leghorn breed of fowls. Amer. Nat., 47, 1913, 418–428.

The manner in which this factor acts, in order to destroy pigment, or to neutralize it, or to prevent its formation, is at present a matter of speculation only. One might assume that there is some fundamental color-substance (C) upon which various color-enzymes act to produce, one black, another red, another buff, etc. Black pigmentation for instance, might be regarded as the result of a color enzyme (N, *nigrum*) acting upon the general color factor C.† Thus, without knowing what factors for pigmentation actually are, it serves our present purpose to assume that one or more factors are necessary for the production of black pigmentation and that the inhibitor, I, through its action upon one or all of them, is able to repress such pigmentation, not only in the White Leghorn itself (provided the factor, or factors, concerned could otherwise determine black pigmentation), but also in F_1 in crosses between the White Leghorn and other breeds characterized by black plumage.

One other character which is possessed by the White Leghorn and which affects the results of crossing in F_2, must be mentioned. This is the barred plumage pattern which, as the writer has already shown,‡ is commonly latent in the White Leghorn stock. The White Leghorn ♂ used in the cross about to be described was homozygous for this character (BB) while the White Plymouth Rock ♀ ♀ were heterozygous (Bb). In accordance with results of studies on barring, carried on by a number of investigators, it can now be assumed safely that the factor for barring is inherited in a sex-limited manner; that is, the character can be transmitted by the males to both male and female progeny, but the barred females are unable to transmit the pattern to their daughters.

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*COLE, L. J., Studies on inheritance in pigeons: I. Hereditary relations of the principal colors, R. I. Agr. Expt. Sta. Bul. 158, 1914.

†DAVENPORT, C. B., Inheritance of characters in the domestic fowl, Publ. No. 52, Carnegie Inst., Washington, 1906.

‡Studies on inheritance in poultry.: I. The constitution of the White Leghorn breed, Rhode Island Agr. Expt. Sta. Bul. 155, pp. 151–216.

Upon the basis of the assumptions mentioned above, and assuming furthermore, that the factor C embodies all that is necessary (in the absence of I) for black pigmentation, the zygotic formula of the White Leghorn ♂ may be written

$$C_2B_2f_2I_2$$

and that of the White Leghorn ♀ as

$$C_2BbFfI_2.$$

On similar grounds the White Plymouth Rock ♂, lacking all pigmentation factors, would be

$$c_2B_2f_2i_2$$

and the White Plymouth Rock ♀

$$c_2BbFfi_2.$$

In case, however, we make the supposition that two distinct factors are required for black pigmentation, and that only one of these (X) is present in the White Leghorn, while the White Plymouth Rock contains the other (Y), the formula of the White Leghorn ♂ becomes

$$B_2f_2I_2X_2y_2$$

and the White Leghorn ♀

$$BbFfI_2X_2y_2.$$

In a similar manner the White Plymouth Rock ♂ would be represented

$$B_2f_2i_2x_2Y_2$$

and the White Plymouth Rock ♀ as

$$BbFfi_2x_2Y_2.$$

The point at issue therefore is this: Which zygotic formula for the White Leghorn ♂ ($C_2B_2f_2I_2$ or $B_2f_2I_2X_2y_2$), and which formula for the White Plymouth Rock ♀♀ (c_2BbFfi_2 or $BbFfi_2x_2Y_2$) furnishes the better interpretation for the experimental results now to be reported.

Experimental Results.

In the breeding season of 1912 White Leghorn ♂, 1A, was mated with White Plymouth Rock ♀♀, 270A and 288A. From this mating 63 chicks were hatched and the majority of them raised to the age of five or six months. Of the 63 F_1 birds, five showed imperfect barring in one or more feathers; many possessed feathers slightly flecked with black, indicating that the inhibitor I was not able, when in heterozygous condition, to hold in check all black pigmentation.

In the breeding season of 1913, an F_1♂, 466C, was mated with four of his sisters, 466E, J, M and P. The male was a nearly pure white bird. Of the females, 466E, J and P were pure white, although as a chick 466J showed patches of black down feathers; 466M put up one barred feather among the right secondary coverts.

This mating gave rise to 103 chicks. The majority were reared to the age of five or six months, and some to maturity. Among the 103 birds were 21 which were either dark colored or possessed the barred pattern; in the majority of these the barring was of poor grade, but in a few it was fair.

In the breeding season of 1914, a brother of the male employed in 1913 (466A) was mated with the three females that remained, 466J, M and P. From this mating, 64 birds were hatched and described. Observations showed that 52 were white and 12 barred or dark colored.

Discussion of Results.

If the W. L. ♂ has the zygotic constitution $C_2B_2f_2I_2$ as indicated on a previous page, it forms gametes

$$CBfI \;.\; CBfI$$

while the W. P. R. ♀, c_2BbFfi_2, forms gametes

$$cBfi \;.\; cbFi.$$

The mating would therefore be represented:

♂ CBfI . CBfI ×
♀ cBfi . cbFi =

♀♀ CcBbFfIi, white
♂♂ CcB_2f_2Ii, white.

In obtaining F_2, the F_1 cross-bred male possessing the formula CcB_2f_2Ii would form gametes of four sorts as follows:

CBfI . CBfi . cBfI . cBfi

while the female cross-bred, possessing the formula CcBbFfIi would form gametes of eight sorts:

CBfI . CBfi . cBfI . cBfi
CbFI . CbFi . cbFI . cbFi

The mating would therefore be represented

♀ CBfI . CBfi . cBfI . cBfi . CbFI . CbFi . cbFI . cbFi ×
♂ CBfI . CBfi . cBfI . cBfi =

	C_2BbFfI_2 (1), white		$C_2B_2f_2I_2$ (1), white
	$C_2BbFfIi$ (2), white		$C_2B_2f_2Ii$ (2), white
	$CcBbFfI_2$ (2), white		$CcB_2f_2I_2$ (2), white
	$CcBbFfIi$ (4), white		CcB_2f_2Ii (4), white
♀♀	c_2BbFfI_2 (1), white	♂♂	$c_2B_2f_2I_2$ (1), white
	$c_2BbFfIi$ (2), white		$c_2B_2f_2Ii$ (2), white
	c_2BbFfi_2 (1), white		$c_2B_2f_2i_2$ (1), white
	C_2BbFfi_2 (1), barred		$C_2B_2f_2i_2$ (1), barred
	$CcBbFfi_2$ (2), barred		$CcB_2f_2i_2$ (2), barred

This may be summarized:

CHARACTER.	♂	♀	Total.
White	13	13	26
Barred	3	3	6
Total	16	16	32

It is thus apparent that among every 32 F_2 individuals, one would expect to obtain six barred birds, equally divided between the sexes. The results of the 1913 breeding season may now be compared with the expectations as follows:

CHARACTER.	Actual.	Expected.
Barred or dark*..................................	21	19.4
White..................................	82	83.6
Totals..................................	103	103.0

It is apparent that there is close accordance between the expected results and those actually obtained in the 1913 breeding pens. We may, however, consider the second series of matings made in the season of 1914.

CHARACTER.	Actual.	Expected.
Barred or dark..................................	12	12
White..................................	52	52
Totals..................................	64	64

In these data, the experimental and the theoretical results find absolute agreement. It was a matter of chance that exactly 64 birds were raised in the 1914 series.

We may now consider the second possible interpretation of the experimental data. By this hypothesis, it is assumed that the W. L. ♂ contains factor X and the W. P. R. ♀ contains factor Y, both X and Y being required for the manifestation of black. In accordance with this view the W. L. ♂ would possess the formula

$$B_2f_2I_2X_2y_2$$

---

*When the chicks are young, the barred individuals are invariably dark, and without evident pattern.

forming gametes

BfIXy . BfIXy

while the W. P. R. ♀ would be

$BbFfi_2x_2Y_2$

forming gametes

BfixY . bFixY

The mating would then be represented

♂ BfIXy . BfIXy ×
♀ BfixY . bFixY =

♂♂ $B_2f_2IiXxYy$, white
♀♀ BbFfIiXxYy, white

In the production of F_2 the F_1 white cross-bred male, $B_2f_2IiXxYy$, would form gametes of eight sorts:

BfIXY . Bfixy . BfIXy . BfixY
BfIxy . BfiXY . BfIxY . BfiXy

while the F_1 white cross-bred female, BbFfIiXxYy, would form gametes of 16 sorts:

BfIXY . Bfixy . bFIXY . bFixy
BfIXy . BfixY . bFIXy . bFixY
BfIxY . BfiXY . bFIxY . bFiXY
BfIxy . BfiXy . bFIxy . bFiXy

This mating would give 128 individuals possessing 27 different zygotic constitutions as follows:

♀♀	♂♂
$BbFfI_2X_2Y_2$ (1), white	$B_2f_2I_2X_2Y_2$ (1), white
BbFfIiXxYy (8), white	$B_2f_2IiXxYy$ (8), white
$BbFfI_2X_2Yy$ (2), white	$B_2f_2I_2X_2Yy$ (2), white
$BbFfIiXxY_2$ (4), white	$B_2f_2IiXxY_2$ (4), white
$BbFfI_2XxYy$ (4), white	$B_2f_2I_2XxYy$ (4), white
$BbFfIiX_2Y_2$ (2), white	$B_2f_2IiX_2Y_2$ (2), white
$BbFfI_2XxY_2$ (2), white	$B_2f_2I_2XxY_2$ (2), white
$BbFfIiX_2Yy$ (4), white	$B_2f_2IiX_2Yy$ (4), white

$BbFfIiXxy_2$ (4), white
$BbFfI_2X_2y_2$ (1), white
$BbFfI_2Xxy_2$ (2), white
$BbFfIiX_2y_2$ (2), white
$BbFfIix_2Yy$ (4), white
$BbFfIix_2Y_2$ (2), white
$BbFfI_2x_2Yy$ (2), white
$BbFfI_2x_2Y_2$ (1), white
$BbFfIix_2y_2$ (2), white
$BbFfI_2x_2y_2$ (1), white
$BbFfi_2x_2y_2$ (1), white
$BbFfi_2x_2Yy$ (2), white
$BbFfi_2X_2y_2$ (1), white
$BbFfi_2Xxy_2$ (2), white
$BbFfi_2x_2Y_2$ (1), white
$BbFfi_2XxYy$ (4), barred
$BbFfi_2XxY_2$ (2), barred
$BbFfi_2X_2Y_2$ (1), barred
$BbFfi_2X_2Yy$ (2), barred

$B_2f_2IiXxy_2$ (4), white
$B_2f_2I_2X_2y_2$ (1), white
$B_2f_2I_2Xxy_2$ (2), white
$B_2f_2IiX_2y_2$ (2), white
$B_2f_2Iix_2Yy$ (4), white
$B_2f_2Iix_2Y_2$ (2), white
$B_2f_2I_2x_2Yy$ (2), white
$B_2f_2I_2x_2Y_2$ (1), white
$B_2f_2Iix_2y_2$ (2), white
$B_2f_2I_2x_2y_2$ (1), white
$B_2f_2i_2x_2y_2$ (1), white
$B_2f_2i_2x_2Yy$ (2), white
$B_2f_2i_2X_2y_2$ (1), white
$B_2f_2i_2Xxy_2$ (2), white
$B_2f_2i_2x_2Y_2$ (1), white
$B_2f_2i_2XxYy$ (4), barred
$B_2f_2i_2XxY_2$ (2), barred
$B_2f_2i_2X_2Y_2$ (1), barred
$B_2f_2i_2X_2Yy$ (2), barred

From this analysis it is apparent that among every 128 individuals 18 would be barred and 110 white, both the barred and the white birds being equally divided between the sexes as follows:

CHARACTER.	♂	♀	Total.
White	55	55	110
Barred or dark	9	9	18
Total	64	64	128

It is thus apparent that, among every 128 individuals, one would expect to find 18 barred birds, equally divided between the sexes. The actual results of the 1913 matings may now be compared with these expectations, derived in accordance with the second hypothesis.

CHARACTER.	Actual.	Expected.
Barred or dark	21	14.5
White	82	88.5
Totals	103	103.0

From this tabulation it is clear that there is a wide departure between the actual and the expected results. And when the 1914 data are compared with the expectations derived from this hypothesis, the departure is still more noticeable, since, in the case of the first hypothesis, there was perfect agreement.

The experimental results for 1913 and 1914 may now be brought together and the data compared with the expected results obtained from both hypotheses.

RESULTS.	1913 MATINGS.			1914 MATINGS.			1913–1914 MATINGS.		
	White.	Dark.	Total.	White.	Dark.	Total.	White.	Dark.	Total.
Actual	82.0	21.0	103	52	12	64	134.0	33.0	167
Expected, first hypothesis	83.6	19.4	103	52	12	64	135.8	31.2	167
Expected, second hypothesis	88.5	14.5	103	55	9	64	143.6	23.4	167

From these data it is apparent that the number of dark colored birds actually obtained in the experimental matings of both 1913 and 1914 exceeded the number called for, on the basis of the first hypothesis by only 1.8, while it exceeded by 9.6 the number called for on the basis of the second hypothesis. It is thus conclusively demonstrated that the first hypothesis best explains the phenomena observed. In other words, the White Leghorn carries in itself all the factors necessary for the production of black pigmentation in the F_2 and later generations of crosses with any non-black race.

In thus demonstrating the constitution of the White Leghorn with reference to factors for black pigmentation these results possess a significance in the field of practical breeding. It is not uncommon for poultrymen to employ the White Leghorn in crosses with other breeds to improve certain characters. In so doing it is usually assumed that since the White Leghorn is ostensibly white, and lacking visible pattern, the admixture of Leghorn blood can be made without introducing complexities in either pattern or color. The results of the present study, as well as the experience of many poultrymen, indicate clearly that such a procedure is open to considerable danger if the breeder desires to foster race-purity in his stock. The fact that the White Leghorn carries both black pigmentation and factors for barred plumage pattern means that in F_2 and later generations these characters may appear to the detriment of the breed. Black, which through years of persevering selection has perhaps been eliminated from buff, may be unconsciously re-introduced under the cloak of the Leghorn dominant white. Dark barrings and cuckoo markings, from which a race may have been quite purified, may re-enter under the apparently patternless feathering of this breed. To know the constitution of the race, to know the factors that lie hidden in the germ plasm, as well as those characters that are on parade, enable the intelligent poultryman to make use of desirable characters to the best advantage; and at the same time, to avoid those errors in breeding which result from insufficient knowledge of the fundamental constitution of the race involved.

(OVER)

Description of Plate I.

Figure 1. White Leghorn male, 23 A.

Figure 2. White Plymouth Rock female.

Figure 3. F_1 male from W. L. × W. P. R. cross.

Figure 4. Type of barred bird obtained in F_2 from W. L. × W. P. R. cross.

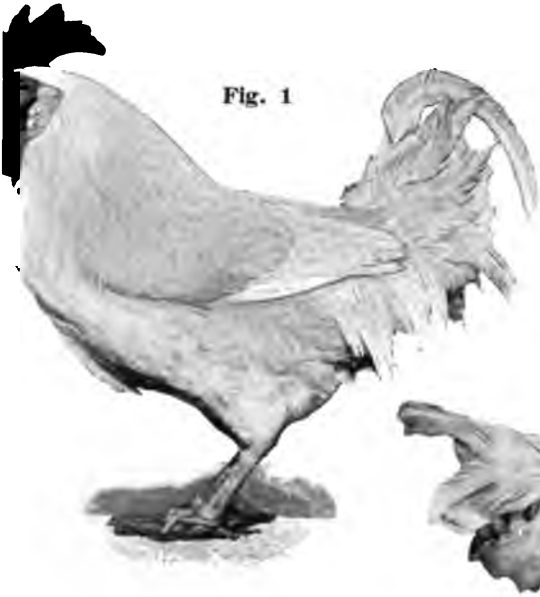


Fig. 1

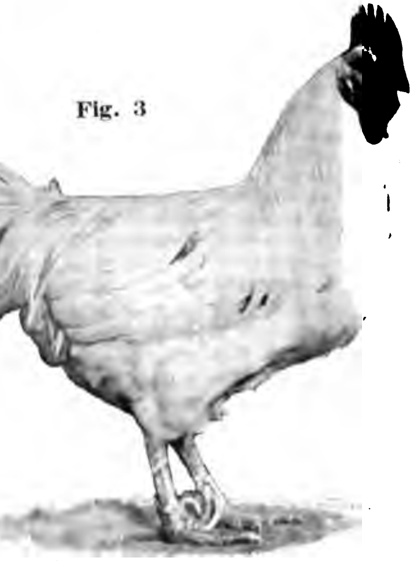
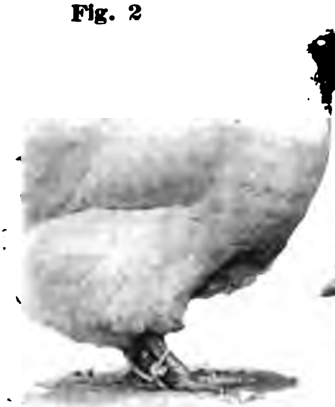


Fig. 3

Fig. 2



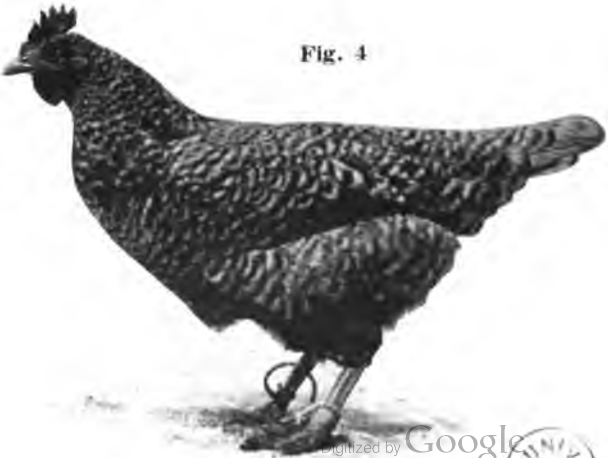


Fig. 4

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Sex Ratios in Pigeons, together with Observations on the Laying, Incubation and Hatching of the Eggs.

BULLETIN 162

Agricultural Experiment Station

OF THE

Rhode Island State College

KINGSTON, R. I., U. S. A., APRIL, 1915

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AGRICULTURAL EXPERIMENT STATION OF THE
RHODE ISLAND STATE COLLEGE.

BULLETIN 162, APRIL, 1915.

SEX RATIOS IN PIGEONS, TOGETHER WITH OBSERVATIONS ON THE LAYING, INCUBATION AND HATCHING OF THE EGGS.*

BY LEON J. COLE AND WILLIAM F. KIRKPATRICK.

Introduction.

The results presented in the present paper have been obtained in the course of studies on inheritance in pigeons, two reports on which have already appeared (Cole, 1914; Lloyd-Jones, 1915). As in the first of these, the data in the present instance have resulted from experiments begun at the Rhode Island Agricultural Experiment Station in 1907, and continued by the senior author at the Wisconsin Experiment Station since the summer of 1910. It is only fair to state that the junior author† had practically full charge of keeping the field notes and taking records up to July, 1910, though the senior author made practically all the descriptions and determinations of sex. All sex determinations are based on the performance of birds which have actually bred, or on dissections. In no case has sex been recorded from the behavior of young birds, unless so verified later.

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*Contribution 215 from the Agricultural Experiment Station of the Rhode Island State College. Papers from the Department of Experimental Breeding of the Wisconsin Agricultural Experiment Station, No. 5.

†Now Professor of Poultry Husbandry, Connecticut Agricultural College, Storrs, Conn.

Since July, 1910, the birds have been more constantly under the observation and care of the senior author, but acknowledgment should be made to Mr. J. C. Curtis and Mr. F. J. Kelley who have at different times assumed a large part of the responsibility for the daily records. Upon the senior author also has devolved the entire writing of the present report.

The subjects here brought together are somewhat disconnected, but for various reasons it seems best to present such data as are available upon them at the present time. The sex ratio in pigeons, and the relation of sex to the order of laying of the eggs are of especial interest because of the prevailing popular notions on the matter, and the fact that these ideas, if true, would be very difficult to explain on the basis of our present knowledge of sex determination and the physiology of egg production in general. As for the time of laying and the time of hatching of the eggs, no statistics we believe have ever been published on these points, though general statements are common in the literature. Our knowledge of the maturation process and the earliest stages of avian embryology are, moreover, based very largely on studies made on the egg of the pigeon, and all accurate information which can be obtained on processes of egg production may be of service in this connection. A knowledge of the most probable time of laying of the second egg may especially be of use in obtaining desired maturation stages. Finally, although the results of the present investigation are largely destructive of the popular notions of sex determination and sex control in pigeons, it is always an advantage for the practical breeder to know the facts, since a knowledge of them may save him much time and effort along fruitless lines.

Investigation on certain of the subjects discussed in this paper is being continued by the Department of Experimental Breeding at the University of Wisconsin, and will subsequently be reported more fully.

Sex Ratio in Pigeons.

Hyperandry, or an excess of males, among pigeons has often been noted, and is occasionally mentioned in current articles on pigeons. It appears to be a matter of common belief among pigeon raisers, in fact, that the males exceed the females in number, and we find the same fact mentioned by Darwin (1875, p. 247), who says: "In regard to domestic pigeons there is good evidence either that the males are produced in excess, or that they live longer; for these birds invariably pair, and single males, as Mr. Tegetmeier informs me, can always be purchased cheaper than females." Darwin submits no definite figures, however, in support of his conclusion. We have, moreover, been unable to find any published figures on the sex ratio of pigeons, except those by Cuénot (1900), who reported on 136 pigeons whose sex was determined soon after hatching. He found 73 males to 63 females, or a ratio of 115.87 to 100, which would mean a relatively pronounced over-production of males.

The proportion of males per 100 females found by Cuénot is considerably higher than we have obtained. Our results for birds of all ages, tabulated to December 24, 1910, were 292 males to 278 females, a ratio of 105.03 to 100. A later tabulation of all sexes determined to July 18, 1914, including the above, gives 845 males to 803 females. This ratio (105.23 to 100) is practically the same as that obtained at the earlier date and since the correspondence is so close, and the numbers are fairly large, it may be assumed that 105:100 represents closely the regular proportion of the sexes in the pigeons we have used.* While these are mostly what are known in this country as Long-faced Tumblers† (both Clean Legged and Muffed), our stock has been derived from various sources and includes also some Parlor Tumbler stock. In addition there are included some, though comparatively few, records of other breeds, especially Homers, which have been used only to a limited extent in our studies. Considering the diversity of origin of the Tumbler stock and the other inclusions it seems quite probable that the ratio of 105 males to 100 females may be taken as the sex ratio for domestic pigeons generally.

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*A still later tabulation was made to December 1, 1914, which added 74 males and 78 females to the list, bringing the total number of known sexes up to exactly 1,800; of these, 919 were males and 881 females, or 104.31 : 100. This slight lowering of the ratio is probably not enough to affect significantly the statement made above.

†They correspond in type to the "Mittelschnäblige" rather than to the "Langschnäblige Tümmler" of the Germans (cf., for example, the illustrations in Schnachtsabel, 1906).

Although the sexes have been determined at different ages in different birds, the combined figures give the sex ratio of all birds hatched whose sex has been determined. There are included, it is true, 81 birds that had not succeeded in emerging completely from the shell at time of death, but whose sex was nevertheless determined. They were therefore recorded technically as "dead in shell," rather than "hatched;" but for reasons which will appear it has seemed inadvisable to separate these birds from those which died within the first few days after hatching. Of these birds "dead in shell," 44 were males and 37 females; their exclusion would give a slightly lower ratio of males actually hatched, but the change would probably not be significant.

Is there a Differential Mortality?

Darwin suggested two explanations for the apparent preponderance of males among adult pigeons; first, that males are produced in greater numbers; second that they live longer, or in other words, that there is a higher relative mortality among the females in early life.* The data here presented seem to show fairly conclusively that his first supposition is correct, that there is a slightly greater production of males; but it is doubtful if this excess is great enough to be noticed ordinarily and to account for the prevailing impression. As to a possible differential mortality, Darwin (1875, p. 247) states, on the authority of Mr. Harrison Weir, that when the nestlings are of opposite sexes, "the hen is generally the weaker of the two, and more liable to perish." Cuénot (1899, p. 491) is the only author we have found who gives any actual data on this point. He states that while there may be some truth in the assertion it certainly is not general, for he examined two young pigeons which were less vigorous than their mates, and which the breeder assured him for that reason were females; in reality one was a female, but the other was a male. In another case he dissected two squabs from the same nest, one of which was very vigorous and should have been a male, the other was less developed, and therefore should have been a female; but this time both were females.

---

*Aristotle (1910, 613^a 24—29) says of ring-doves and turtle-doves, "The male, as a general rule, is more long-lived than the female; but in the case of pigeons some assert that the male dies before the female, taking their inference from the statements of persons who keep decoy-birds in captivity."

On this point we have 60 cases to report. These records were made at Wisconsin by Mr. F. J. Kelley, who has kindly tabulated them for us. They show the relation of sex to the relative size of the two squabs at the time of banding, which means at the age of 10 to 15 days. The cases recorded include only those in which there was a fairly well-marked difference in size, and in which the squabs had remained in the same nest and under the same conditions so far as could be told. The data may be summarized as follows:

Larger	squab	♂,	smaller	squab	♀..........	23	cases.
"	"	♀,	"	"	♂.........	4	cases.
"	"	♂,	"	"	♂.........	13	cases.
"	"	♀,	"	"	♀..........	16	cases.
"	"	Unknown,	"	"	♂.........	2	cases.
"	"	"	"	"	♀.........	1	case.
"	"	♀,	"	"	Unknown....	1	case.

Total sexes—large squab = 36 ♂♂ : 21 ♀♀
small squab = 19 ♂♂ : 40 ♀♀
55 ♂♂ : 61 ♀♀

These data certainly seem to lend considerable support to the idea that the larger squabs are in a significant majority of the cases males. A consideration of cases in which one squab died before banding shows less striking results. The argument in this case would be that the female squabs are smaller and less vigorous, more of them would die than of males, and therefore there would be a correspondingly higher percentage of males at the time of banding. In the following pages these points are examined critically on the basis of a larger number of data, other age limits being used, however, than age at banding. Data to support this contention are furnished, and we have therefore examined our records with a view to determining its validity.

From our records to December 1, 1914, the age at time of death of 1,227 birds not including those killed can be determined, and for convenience these have been divided into four groups, one of which seems to have a natural basis, whereas the limits of the other three are more or less artificial. These may be defined as follows:

GROUP A. *Hatching period.* Embryos which were fully developed but which failed to hatch ("dead in shell") and birds which died within five days after hatching.

GROUP B. *Nestling period.* Squabs dying at from 6 to 28 days, inclusive.

GROUP C. *Immature or juvenile period.* Squabs living over 28 days, but dying before six months of age.

GROUP D. *Adult period.* All birds living to the age of six months or more.

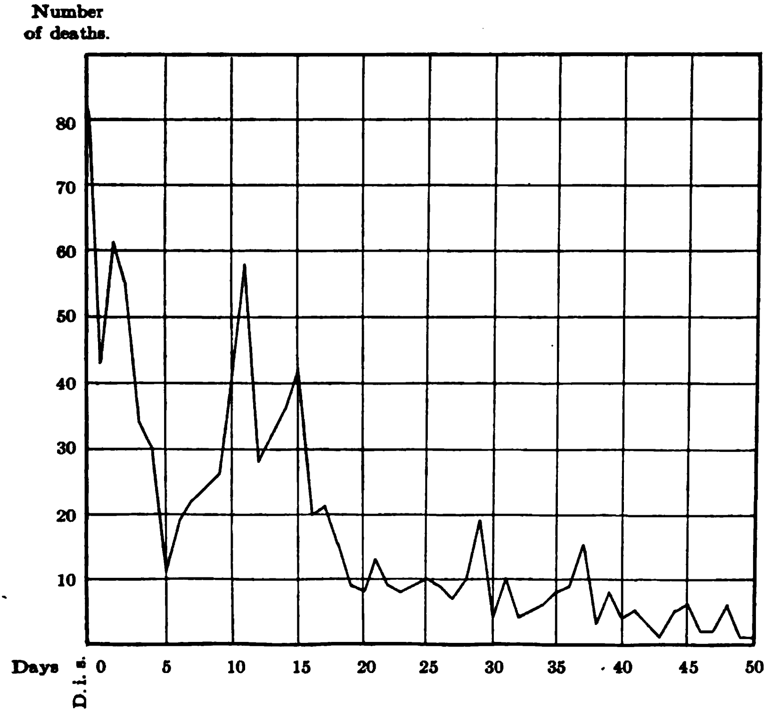

FIG. 1. Number of squabs dying at each day of age up to fifty days. D. i. s., dead in shell; 0, day of hatching; 1, one day old; etc.

In Figure 1 is represented the number of birds dying at each age, at one day intervals, up to 50 days. In the "dead in shell" column only those embryos are included whose sex was determined. The number of fertile eggs which failed for one reason or another to hatch was, of course, very much larger.

Since records are systematically taken once daily, the recorded age at death is usually correct within that period; in a comparatively small number of cases a bird may have been dead for a somewhat longer period before discovered, and there are included records of some birds which were killed because so sick it was evident they would not recover and that death would probably have intervened within a short time. These slight inaccuracies tend to offset one another, and are of little or no consequence so far as the general results are concerned.

It has been found inexpedient to attempt any classification on the basis of the cause of death, since in so many cases this could not be determined and has not been uniformly recorded. Death may result from a great variety of causes, among which perhaps the most important are lack of constitutional vigor, neglect by the parents (especially during cold weather), specific infections, and accidents, especially those resulting from the fighting and interference of adult birds.

Figure 1 shows a high incidence of deaths at time of hatching which rapidly declines to a minimum on the fifth day, after which there is a correspondingly rapid rise to a marked mode from the tenth to fifteenth days. The first two or three days and the tenth to fifteenth days after hatching appear, therefore, to be the most critical periods in the life of the young squabs. The minor irregularities probably have little meaning, and in most cases no explanation is apparent, as for example, the much greater number of deaths on the eleventh day than on the twelfth. On the other hand the greater height of column 1 over the 0 column is probably due to the fact that many squabs living only a few hours after hatching are really not recorded as dead until the following day. There can be no doubt, however, that the marked depression in the death rate at the fifth and sixth days is of significance, and this point has therefore been chosen as the limit between the deaths at hatching and immediately following, and those grouped around the age of about two weeks. From this time the number of deaths drops off again rapidly, and the curve then swings out gradually to about 50 days, after which there is a steady but slight decrease in the number of deaths per month for the full period of nearly six and one-half years since the first squabs were produced in our experimental work. It must be borne in mind, however, that this gradual decrease in the number of deaths recorded does not necessarily imply a decreasing death rate, in fact probably the reverse is true. The death rate at any age should be based on the number of deaths in proportion to the total number of individuals of that age, and this number rapidly decreases in our flock with advanced age as the birds die off, are killed, or are otherwise disposed of. Since therefore it would be very difficult or practically impossible for us to calculate the total population and age composition of our flock for the period under discussion, it is impossible to give any curve which represents accurately the death rate in our pigeons.

The point of interest which appears from the statistics (see Fig. 1) presented is that no such definite demarkations exist for separating Groups B, C and D from one another as marks Group A off from Group B. These groups were in fact established before the tabulation of deaths was made, on the basis of the life cycle of the birds. Twenty-eight days was taken as marking approximately the termination of the nestling stage, since at that age most squabs have left the nest. Six months was chosen arbitrarily for the beginning of the adult stage as representing approximately the average age at which pigeons are sexually mature and may begin breeding if conditions are favorable. It is true that a few early hatched birds may breed the same season, but the great majority do not begin until the following year.

With the above classification as a basis we may now examine the question of a differential mortality. In order to test the statement quoted from Darwin (p. 465) tabulations have been made of cases in which the two nestlings were known to be of opposite sex and one or both died before reaching adult life (period D). A total of 172 such cases is recorded: in 88 of these the male died first and was survived for a longer or shorter period by his female nestmate; in 84 cases the female died first and was survived by the male. Since these figures relate only to bisexual broods, the number of males and females hatched was equal, namely, 172 of each.* The excess of four male deaths over the female deaths is so slight as probably not to be significant, so we may say that the death rate for the two sexes was also essentially equal.

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*The excess of males hatched (in the ratio of 105 : 100; cf. p. 465) must be accounted for by an excess of male unisexual broods, or by a greater number of males among broods containing but a single squab.

In more than half the cases enumerated above, the surviving member of each pair of squabs failed to reach maturity; since both therefore died before six months of age, they in no way influenced the sex proportions in Group D. Summarizing those cases in which one member of the bisexual pair of nestlings died before six months and the other exceeded that period we find a total of 68 examples,—31 in which the male died and the female survived, 37 in which the female died and the male attained the adult stage. While the number of female deaths in Groups A, B and C is here somewhat larger, it should be borne in mind that the number of cases is relatively small, and that we are dealing only with bisexual broods which happened to meet these conditions. So far as the above figures go, therefore, they seem to show that there is no marked tendency for one sex to be weaker than the other in bisexual broods, and there is only slight indication that male survivors may exceed female survivors in reaching the adult stage as here defined.

TABLE I.—*Composition of population and number of deaths with respect to sex in the different age periods.*

Age period.	Population.			Deaths.		Per cent. of population which died.		Ratio of ♂ deaths to 100 ♀ deaths.
	♂♂	♀♀	♂♂ : 100 ♀♀	♂♂	♀♀	♂♂	♀♀	
A.......	866	810	106.9	115	114	13.3	14.1	100.9
B.......	751	696	107.9	228	193	30.4	27.7	118.1
C.......	523	503	105.0	135	142	25.8	28.2	95.1
D.......	388	361	107.5	388*	361*	100.0	100.0	107.5

The distribution of deaths with respect to age and sex (using the age-groups which have been defined) is shown in Table I, the age period at time of death being known for 1,676 birds* whose sex was determined as well. Of these 1,676 pigeons, 866 were males and 810 were females, the ratio being 106.9 : 100. While this ratio is slightly higher than that (105 : 100) which has been taken as normal, the difference is not great enough to be of much significance, and for present purposes we only therefore consider the changes in a population assumed to consist at hatching of 866 males and 810 females, all other birds being left out of consideration for the time being. In Period A, that is, within five days of hatching, 115, or 13.3% of the original number of males died, and 114, or 14.1% of the females. The number of deaths of each sex is almost equal (100.9 : 100), there being one more male death than female, but the *percentage* of female deaths is slightly greater.

---

*This does not mean that all these birds were yet dead at the time of tabulation, but when their death occurs it will of course be in this period.

Subtracting the deaths in Period A leaves the population in Period B composed of 751 males and 696 females, or 107.9 : 100, a slightly higher proportion of males than before. In this period the number of male deaths considerably exceeds the female deaths, there being 228 of the former and 193 of the latter (118.1 : 100). The proportion of the males which died in Period B is 30.4%; of the females, 27.7%. The distinctly higher death rate of males in the nestling period is reflected in the composition of the juvenile population (523 males, 503 females), where the proportion of males (105 : 100) is lower than at the start. Period C is the only one in which the actual number of female deaths exceeds the male deaths, and the only one in which the percentage of female deaths is in excess to any appreciable degree. The ratio of male to female deaths is 95.1 : 100; expressed in percents, 25.8% of the males composing the population died, 28.2% of the females. Allowing now for all previous deaths we find that the adult population (Period D), consisting of 749 birds, comprises 388 males and 361 females, or only a slightly, and probably insignificantly higher ratio of males (107.5 : 100) than that with which we started.

---

*In addition to the 1,227 birds mentioned on page 468 there are here included those birds which were killed after they were six months of age, and birds over six months of age alive on December 1, 1914, whose sex had been determined by their breeding behavior. It is certain, therefore, that all these belonged to Group C.

A review of the proportion of males to females in the different age periods displays surprisingly little fluctuation, it never being greater than 107.9 nor less than 105. Certainly these differences are not great enough to account for the prevailing impression of the higher mortality of females in the earlier stages, and do not furnish any substantiation of such a notion.

There still remains the possibility of a difference in the death rate of the two sexes after reaching what we have called adult life, and this will be examined next. This group, it will be recalled, includes 749 birds which attained the age of six months or more. Of these 125 died from "natural" causes, 391 were alive on December 1, 1914, and 233 were killed, sold, or otherwise disposed of at periods presumably shorter than would have been their natural space of life. Table II summarizes the data for the first two classes—those which died natural deaths and those which were alive at the time of compilation. These two classes together represent a total of 516 birds, the *females* being considerably in excess. The numbers are, 244 males and 272 females. For purposes of tabulation they have been divided into periods of 1 year, except the first group, which is only a six-month period, including birds between six months and one year of age.

TABLE II.—*Adult birds alive and which have died at specified ages.*

AGE.	6 mos.—1 yr.		1 yr.—2 yrs.		2 yrs.—3 yrs.		3 yrs.—4 yrs.		4 yrs.—5 yrs.		5 yrs.—6 yrs.		6 yrs.—7 yrs.		7 yrs.—8 yrs.		Totals.	
SEX.	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀
Total reaching given age	244	272	229	248	210	214	206	203	201	199	200	195	198	194	197	194	....	....
No. which died at given age	15	24	19	34	4	11	5	4	1	4	2	1	1	0	0	0	47	78
Alive December 1, 1914	1	0	23	31	81	88	65	55	13	11	8	6	2	1	4	2	197	194
Totals	16	24	42	65	85	99	70	59	14	15	10	7	3	1	4	2	244	272
Per cent. dead of total reaching given age	6.1	....	8.3	....	1.9	....	2.4	....	0.5	....	1.0	....	0.5	....	0.0	....	....	....
	....	8.8	....	13.7	....	5.1	....	2.0	....	2.0	....	0.5	....	0.0	....	0.0	....	....

Perhaps the most striking fact noticeable in this table is that from the age of six months to three years the number of females which died is strikingly in excess of the males. To a less extent the same is true (except in the six-month group)* of the number of females alive on December 1, 1914, as compared with the males. Beyond this age the numbers dead are so small that they have little meaning; it will be observed, however, that in the case of the birds alive at ages above three years the earlier condition is reversed, there being more males than females alive at each age above three years. The total number of female deaths in the adult period is greatly in excess of the male deaths, there being 78 of the former recorded and only 47 of the latter. By far the greater number of these occurred under the age of two years. At the bottom of the table the number of deaths for each sex is given as a percentage of the total number of birds which reached that age, the sexes again being considered separately. These show that the highest percentage of the females died between the ages of one and two years, and in each group up to three years the percentage of females which died is considerably greater than of males; beyond this point the figures are scarcely significant.

Considering the birds alive, it will be seen that there are somewhat more one-and two-year-old females than males; but of the older ages the males are always in excess, so that the total number of males slightly exceeds the females, being 197 as against 194, a ratio (101.6: 100) distinctly lower than the normal ratio at hatching.

Summarizing the results of Table II, they seem to show that there is a high mortality of both sexes during the first two or three years of their adult life, but that it is especially high in the females between the ages of one and two years. The difference between the percentage of female and male deaths is considerably greater at this age than at any other and it seems not unlikely that this may be associated with trouble connected with the onset of ovulation. This greater mortality of females in the early adult ages, together with the somewhat greater number of males hatched, may account for the prevailing impression of the considerably greater proportion of males among adult pigeons. It may be recalled, however, that in the total number of pigeons reaching adult age (Period D; see Table I) there was a preponderance of males even beyond that at hatching and it is natural to ask what has become of these. If we turn to the 233 birds "killed, sold or otherwise disposed of" after reaching six months of age we obtain considerable light on this point, for only 89 of them were females and 144 were males. In other words, we have practically equalized the effects of the greater mortality of females by a selection favoring males in eliminating birds from the flock.

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*Living birds hatched before June in 1914, and consequently over six months old on December 1, are not included, since their sexes are undetermined. The one male less than one year old at this date was hatched in December, 1913.

There seems then to be real substantiation for the idea that male pigeons are commonly in actual excess in adult populations. The impression of an excess of males may, moreover, be accentuated by certain facts in their behavior. The male birds display their sexual characteristics, as a rule, at a considerably younger age than do the females. Sexual behavior is, however, far from an invariable criterion of sex in young birds; while it presents itself in a positive way in many young cocks—by cooing, strutting and fighting—it is largely negative in the hens and in the less aggressive or backward cocks. As a consequence the breeder soon comes to recognize a considerable number of his young males, while the remainder of the young stock remains as an undetermined residuum. The males are thus more conspicuous, and in this way an impression may be gained of a larger proportion of them than actually exists.

It should be emphasized again in this connection that the data here presented pertain only to our own flock. It is possible that different results may obtain under different conditions. We believe, however, that our conditions are fairly representative in most respects, and that the conclusion here reached may be capable of general application.

The Ratio of Bisexual to Unisexual Broods and the Relation of Sex to the Order of Laying of the Eggs.

Domestic pigeons ordinarily lay two eggs at each nesting, and it is another prevalent notion among pigeon breeders that these always, or at least in a majority of instances, give rise to a pair of squabs, that is, to one of each sex. Furthermore, it is commonly maintained that the first egg of the two laid produces a male, while a female is hatched from the second egg of the clutch. This belief is not only firmly established now, but goes far back into antiquity, for Aristotle (1910, 562^b) has the following to say on the subject. "Birds of the pigeon kind, such as the ring-dove and the turtle-dove, lay two eggs at a time; that is to say, they do as a general rule, and they never lay more than three." "The hen-pigeon, as has been said, occasionally lays three eggs, but it never rears more than two chicks, and sometimes rears only one; and the odd one is always a wind-egg."* "The pigeon, as a rule, lays a male egg and a female egg, and generally lays the male egg first; after laying it allows a day's interval to ensue and then lays the second egg."

A point as interesting as this could scarcely be expected to escape Darwin, and indeed in connection with his statements previously referred to (Darwin, 1875, p. 247) he has the following to say on this matter: "Usually the two birds reared from the two eggs laid in the same nest are a male and a female; but Mr. Harrison Weir, who has been so large a breeder, says that he has often bred two cocks from the same nest, and seldom two hens." Little serious attention appears to have been given to settling the matter, however, until it was taken up by Cuénot. This author first gives the subject considerable attention in a general paper on the determination of sex in animals (Cuénot, 1899) and reviews the literature up to his time. Most of his references have been inaccessible to us, but for the sake of completeness we include a summary of the observations and the citations to the original sources as given by him.

---

*The term "wind-egg" was formerly applied loosely to any imperfect, soft-shelled, unimpregnated or addled egg; its use is now obsolete.

Flourens (1864), in eleven broods found in each case a male and a female; Bailly-Maitre, cited by Giard (1897), while admitting that each clutch generally gives a male and a female, reports a pair of common Mondains which three times in succession gave two males in each brood; neither did De Brisay, also cited by Giard (1897), admit this as a general rule, for he had a pair of "Pigeons satin" which in six years produced some half-hundred young, of which only two were females, and a pair of "Colombes diamant," which of 13 young produced a large majority of females. Similarly, Thauziès, a breeder of homing pigeons, cited by H. De Varigny (1898), considers it rather rare that the two young are of different sexes, and reports that in 7 nestings two males were obtained 5 times, two females once, and a male and a female only once; one pair of birds produced nothing but males during three consecutive years. Remy Saint-Loup (1898), raised two Ring-doves* captured in the same nest and both proved to be males.

Cuénot's own observations at that time were not extensive; he reports having examined 9 broods,† after assuring himself with great care that the two eggs came from the same mother, and of these he found that 2 gave both males, 2 gave both females, and in 5 cases there was a male and a female. Cuénot concludes that while it is certain that the young from the two eggs laid at a time by a pigeon are frequently a male and a female, it is no less certain that they are often of the same sex; in view of the conflicting data he suggests that the proportion of bisexual and unisexual broods may vary in the different races and sub-races of pigeons.

As to the order of the sexes in the bisexual broods, Cuénot states that Flourens (1864), reported the first-laid a male in each of the eleven cases examined by him. Cuénot himself presents the results of three observations, in each of which also he found the squab from the first egg was a male, while that from the second was a female; he was unable, however, to note any constant relation of sex to the weight or shape of the egg.

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*Presumably *Columba palumbus;* not *Turtur* (*Streptopelia*) *risorius.*

†Cuénot says he examined "8 pontes" but they sum up to 9, as indicated above.

In a later paper Cuénot (1900), presents much fuller data. He reports 65 broods of homing pigeons in all of which he made certain that both eggs were from the same female. The results were: 17 broods, both males; 14 broods, both females; 34 broods, a male and a female. By chance, as, for example, by tossing two coins, the expectation for 64 throws would be two heads 16 times, two tails 16 times and a head and a tail 32 times. He points out, however, that we must take into account that there were 68 males and only 62 females; correcting for this, chance distribution gives the expectation of both males 17.7 times, both females 14.7 times, and one of each 32.4 times, which is almost exactly the result obtained. It is therefore necessary he concludes, to abandon the fallacy of the bisexuality of the broods, beyond what would be expected from chance.

Further observations caused him to alter also his earlier conclusion as to the proportion of cases in which the first egg produces a male. The first egg was marked before the second was laid in 30 cases, and both squabs were dissected two days before they were due to hatch. In 15 of the cases the first egg produced a male, and in the other 15 cases a female. It appears also, therefore, to be a matter of chance whether the first egg laid is male or female. Cuénot thinks it probable that Flourens did not make his observations himself, but trusted to a subordinate.

At the time we began our observations we were unaware of Cuénot's work. While the popular notions seemed *a priori* extremely improbable, if they were true they presented some very interesting and important theoretical as well as practical problems, and it seemed advisable to accumulate as many data on this phase of the pigeon work as could be done consistently with the studies on inheritance.

If it should prove true that there is a constant relation between the order of the laying of the eggs and the sex of the squabs hatched from them, or indeed if there should be a greater tendency in this direction than could be accounted for by chance, it would be necessary to abandon, or materially to modify, the theory which seems generally so well established, that sex is irrevocably determined by chance at the time of fertilization of the egg. Furthermore, it is difficult to conceive by what sort of mechanism a relationship of this sort could be effected, especially when we consider the irregularities which may occur in the egg laying of the pigeon. While it is true that they ordinarily lay two eggs at each nesting, it is not at all uncommon among domestic pigeons for the hen to lay only one, especially towards the beginning or end of the season; and there are occasionally females which seldom or never lay more than one egg at a sitting. On the other hand, according to various authors (see, for example, quotation from Aristotle, p 478) they may occasionally lay three or even four (Wright, 1879, p. 33). Tegetmeier (1868, p. 10) asserts, however, that they never lay more than two eggs in a nest "unless, from the absence of a sufficient number of male birds, two hens pair and make a nest, when four are laid, which of course are sterile, and after being sat upon for the usual period are deserted." We have had cases of three eggs, but none in which we could be absolutely certain that the third egg was laid by the same bird, though the cicumstantial evidence to that effect was strong. In at least one case the third egg hatched normally.

Certain birds, at least, that normally lay clutches consisting of a considerable number of eggs, may be induced to continue laying for a longer or shorter time if the eggs are removed as laid. This is the case with most of our domestic poultry, such as the ordinary hen, duck, goose, turkey, and so on. The classical example of a non-domesticated bird which has often been made to produce an unusual number of eggs in this way is the Flicker (*Colaptes auratus*). The usual clutch of the Flicker is from 6 to 9 eggs, but much larger numbers may be obtained if the eggs, or all but a "nest egg," are removed as laid, the largest record being of 71 eggs laid in 73 days, beginning about May 6th. Burns (1900, p. 45) has given a summary of such cases for the Flicker, and also for a number of other wild birds. With pigeons, however, removal of the first egg is ineffective in inducing the female to lay any more than two at a time; nor have we yet found any method by which this result may be brought about. The only experiments on wild species which normally lay a restricted number that we have found mentioned are some tests which Levick (1914, p. 127) made in the Antarctic with McCormick's Skua (*Megalestris maccormicki*). As in the pigeon the normal complement of this gull is only two eggs. Levick says: "In order to find out how many eggs a Skua would lay, I marked some nests, and took the eggs as they were laid. In each case a second egg was laid, but when this was taken no more appeared. In two nests I removed the first egg as soon as it was laid, but left the second, which was then sat upon by the parent, who was content with it, or unable to lay a third." It would appear that in birds which normally lay so few eggs at a time, the stimulus for further production caused by removing the eggs, does not occur early enough to allow for continuous production.

Considering the matter from a genetic or phylogenetic standpoint, it would be surprising if a definite relationship of sex to the two eggs of the set were to have become established in one group of pigeons and not in all. This can hardly be the case, however, for while two is the usual number there is apparently no uniformity in this respect in different members of the family Columbidae, or even within the genus Columba. The Red-billed Pigeon (*Columba flavirostris*), for example, is reported to lay but a single egg at each nesting; the Passenger Pigeon (*Ectopistes migratorius*), formerly so abundant in North America, but now extinct, ordinarily laid but a single egg, but sometimes laid two; the Blue-headed Quail-dove (*Starnoenas cyanocephala*) lays one or two; while it is stated that the Mourning Dove (*Zenaidura macroura*) may even lay three or four (Davie, 1889, p. 157). Inglis (1899) reports the laying of three eggs in a nest by a Bengal Green Pigeon (*C. phoenicopterus*). These records are from nests taken in the open, so of course the possibility of the extra eggs having been laid by a different female cannot be entirely excluded.

The relation which the popularly assumed facts, if true, might bear to practical pigeon breeding is illustrated by directions which appeared in a pigeon paper a few years ago for enabling the breeder to maintain an equality of sexes in his breeding stock. The same general idea is fairly current, and appears from time to time in the pigeon magazines. The article referred to first stated that the difficulty the breeder commonly experiences is that at the beginning of the breeding season he finds he has an excess of males in the stock he has saved for breeding. If this difference is very great it may mean considerable loss to a breeder raising squabs for market on a large scale. To avoid this difficulty the author made suggestions of procedure based on certain definite assumptions, somewhat as follows: (a) A pair of squabs, that is a male and a female, is hatched from each complement of two eggs; (b) the first egg laid produces the male, the second egg gives rise to the female; (c) the first egg being laid a considerable time in advance of the second, hatches first, and therefore (d) the time of incubation being the same for both eggs, it follows that (e) the first squab to hatch is a male, while the female hatches sometime later; (f) as a consequence of being hatched earlier the male gets a start in growth over the female, and consequently (g) the larger squab of a brood is a male and the smaller a female. From these assumptions the conclusion was drawn that in order to obtain an equal number of males and females all the breeder need do would be to separate the two members of each brood while he still knew which they were, putting the larger squab in each case into one pen and the smaller into another. He would then have one pen of males and the other of females and he could choose from them to suit his convenience.

Directions depending upon much the same assumptions are given by Wright (1879, p. 33). Speaking of the two eggs of a set he says, "These two are in three cases out of four a cock and a hen, but by no means always so, as usually supposed; about twenty-five per cent. being pairs of one sex or the other. When one is a hen it is generally the last of the two, and as such likely to be stunted in growth from the earlier hatching of the first, which has had a start by the hen standing over it before the other was laid, and thus gets fed and becomes larger and stronger before the hen is hatched. To avoid this, laying should be watched for every evening, and the first egg taken away and replaced by a nest egg of bone or a waste pigeon's egg, to be replaced the evening the second is laid. This plan will save or improve many a hen that otherwise would be dwarfed in rearing." No figures are advanced in substantiation of the statements made.

Assumptions (*a*) and (*b*) have both been disproven by the observations of Cuénot (1900), and our results support his. Our general conclusions were published in abstract several years ago (Cole, 1911); since then we have added many more corroborative data, all of which are presented below. Assumptions (*c*), (*d*) and (*e*) are considered in a later section; data bearing on (*f*) and (*g*) have already been presented. Briefly, it may be said that none of these assumptions is true in its entirety; some are partially true, while others have no foundation whatever in fact. It will be noted that among these no mention is made of an excess of males hatched, one fact helping to explain their reputed excess in the breeders' lofts which appears to be well established.

Our data showing the relation of sex to order of laying of the eggs, summarized to July 18, 1914, are presented in Table III.

TABLE III.—*Sex of squabs in relation to order of laying of eggs.*

Row.	FIRST EGG.	A♂	A♀	A♂	A♀	A♂	A♀	A–	A–	X(Y)♂	X(Y)♂	X(Y)♀	X(Y)♂	X(Y)♀	A♂	A♀	Totals.	Row.
	SECOND EGG.	B♀	B♂	B♂	B♀	B–	B–	B♂	B♀	X(Y)♀	X(Y)♂	X(Y)♀	X(Y)–	X(Y)–	–	–		
	Records																	
1	Rhode Island	41	41	43	55	36	39	50	19	13	7	4	4	5	7	2	366	1
2	Wisconsin	6	7			44	32	42	37	176	99	94	64	63	16	16	696	2
	Totals																	
3	Broods	47	48	43	55	80	71	92	56	189	106	98	68	68	23	18	1,062	3
4	Individuals	94	96	86	110	80	71	92	56	378	212	196	68	68	23	18	1,648	4
5	Males	47	48	86		80		92		189	212		68		23		845	5
6	Females	47	48		110		71		56	189		196		68		18	803	6
7	A males	47		43		80					106				23		299	7
8	A females		48		55		71					98				18	290	8
9	B males		48	43				92			106						289	9
10	B females	47			55				56			98					256	10
11	♂♀ or ♀♂ broods	47	48							189							284	11
12	♂♂ or ♀♀ broods			43	55						106	98					302	12
13	♂♂ broods			43							106						149	13
14	♀♀ broods				55							98					153	14
15	♂♂ In broods in which sex of both squabs was determined	47	48	86						189	212						582	15
16	♀♀ In broods in which sex of both squabs was determined	47	48		110					189		196					590	16

This table contains also other records of known sexes, thus giving the complete total of sexes determined to that date, but the ratio obtained from these numbers has already been discussed on (p. 465). The first egg laid is designated the "A" egg, while the second is egg "B;" similarly the squabs from the two eggs are designated "A" and "B" according to the respective eggs from which they hatched. In case both eggs were laid before they were found, so that the order of laying was unknown, or if it was not determined which squab hatched from which egg, they are referred to as eggs "X" and "Y" or squabs "X" and "Y" to designate this fact. It is a part of the daily routine to mark the newly laid eggs. In the work at the Rhode Island Station one of the eggs was removed to the incubator a day or so before it was due to hatch; the squab hatching from it was marked by a thread tied loosely around the leg, and was then returned to the nest. The thread was removed when the permanent legband was put on at the age of 10 to 15 days.*

The first four columns of Table III record the cases in which the sex of both A and B are known; in the next four columns only one, either A or B, is known, the other egg having been sterile, accidently broken, or the sex for some other reason indeterminable. In the following three columns the sex of both squabs is known, but not the order of laying of the eggs, or else it is not known from which egg a particular squab came. The following two columns show the sex of only one of the squabs under similar conditions; and finally in the last two columns are those cases in which but a single egg was laid, it being designated "A" accordingly.

The results of interest in the present connection are shown in the combined summaries in the rows in the lower part of the table. Rows 5 and 6 show a total of 845 males to 803 females, or a ratio of 105 : 100, which we have considered as normal. By comparing rows 7 and 8, in which the proportion of total males to total females is nearly 108 : 100, we find that of the 589 known A-eggs, 299 produced males and 290 females. This is a ratio of only 103 : 100; in other words, *the excess of males from A-eggs is slightly less in this case than normal for both eggs.* As would be expected, we find a correspondingly larger proportion of males to females from B-eggs, namely 289 males to 256 females (rows 9 and 10), or 113 : 100. This result confirms that which Cuénot obtained with small numbers, to the effect that there is no basis in fact for the belief that the A-egg more often produces males and the B-egg females.

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*A much simpler method of marking young squabs for identification purposes is now employed. With scissors the claw of any desired toe may be clipped off on young squabs, without bleeding, and without causing the bird any apparent pain. If clipped back beyond the growing region this gives a permanent mark by which the bird may be identified through life. We depend upon it, of course, only until the permanent band is put on.

Considering now only those cases in which the sexes of both squabs were determined, we note (rows 11 and 12) that there were 284 bisexual broods to 302 unisexual, and that of the latter 149 consisted of two males and 153 of two females (rows 13 and 14). The expectation, if we assume that sex is determined by chance, would be equality in both instances. In the ratio of bisexual to unisexual broods the chances are about even that the divergence from equality would be as great as that observed, with the odds very slightly against it.* On the other hand the ratio of 149 broods 'both males' to 153 broods 'both females' is well within expectation.† While, therefore, the numbers of the bisexual and unisexual broods are rather divergent, they are not so far apart as to demand any other explanation than that of a chance result, and for practical purposes the male as compared with the female broods may be considered as equal. It happens that there are four more of the latter than of the former, and therefore the total number of females in the broods in which the sex of both squabs was determined exceeds the total number of males by 8 (rows 15 and 16). This difference, of course, cannot be taken as having any significance.

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*Ratio obtained, 284 : 302.

Deviation from equality = 9.

Probable error ($0.67449\sqrt{npq}$; n, number of individuals, p and q, proportions expected in each class, in this case ½ in each) = 8.1638.

$\frac{\text{Deviation}}{\text{Probable error}} = 1.1.$ The odds against a deviation as great as 9 are accordingly 1.18 to 1 (Pearl and Miner, 1914).

†Ratio obtained = 149 : 153.

Deviation = 2.

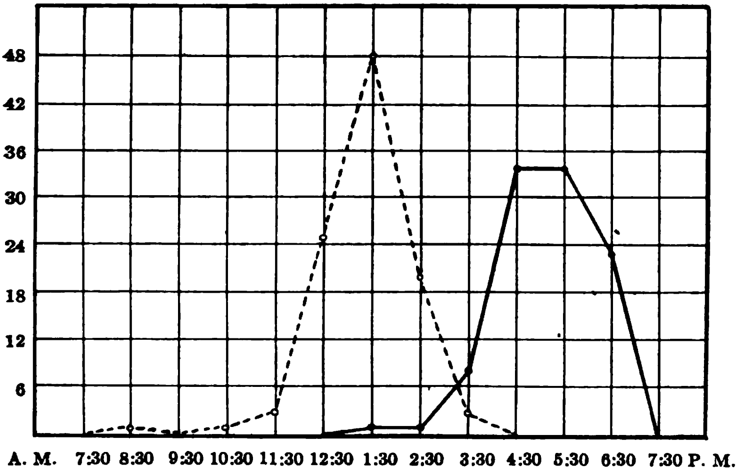
P. E. = 5.86.

$\frac{\text{D}}{\text{P. E.}} = 0.34.$

Time of Laying of Eggs A and B.

That a day intervenes between the laying of the two eggs is a fact known by all breeders of pigeons, but no accurate study of the time of laying appears to have been made. The statement by Wright is more definite in this respect than most. He says (Wright, 1879, p. 33): "Soon after matching—generally ranging from one to three weeks, according to age and time of year—the cock will begin to drive the hen towards her nest, and seem uneasy whenever she is away from it. That is a sign laying is near, and in fact the eggs generally appear in from two to five days after. Two are laid; the first usually about five or six o'clock in the afternoon, the hen standing more or less over it all the next day and night, and laying the second egg about two o'clock on the third day."

During the first eighteen months of our work an attempt was made to obtain as accurate records as possible of the time of laying and of hatching of the eggs. A routine was established of making hourly observations from 7 A. M. to 8 P. M., and this was adhered to as far as conditions permitted. As a result we have records of 101 sets of eggs, the time of laying of each of which is known within the limits of one hour; 12 of these records are scattered through 1907, while the remaining 89 were made during the months of January to July, inclusive, in 1908. In many cases the time of laying is known more closely than the limit here ascribed, but for statistical treatment the records have been grouped into one-hour classes, the mid-value of the class being the half hour. Such records as fall exactly on the even hour have been uniformly placed in the class preceding that hour; for example, an egg recorded as laid at 4 P. M. has been classed as 3—4 P. M. We have many other records in which the time of laying is known within a somewhat longer period than one hour, but such records have not been included in the present discussion.



Frequencies.	7:30	8:30	9:30	10:30	11:30	12:30	1:30	2:30	3:30	4:30	5:30	6:30	7:30
A-egg.							1	1	8	34	34	23	
B-egg.		1	0	1	3	25	48	20	3				

FIG. 2. Curves showing time of day the two eggs were laid in 101 sets; solid line, first egg; dotted line, second egg, on second day following first.

The distribution of frequencies with respect to the time of laying of both eggs is shown in Figure 2. The unbroken line represents the data for the first egg, the broken line for the second; but it must be remembered that although for convenience of comparison the two curves are here superimposed, in reality egg B is laid on the second day following egg A, and that therefore there is a period of nearly 48 hours between the two curves. The frequencies for the respective classes are given below the figure. Basing our statements entirely on the data here presented, we may draw the following conclusions:

1. Egg A is always laid in the afternoon, some time between the hours of one and seven.

2. Egg A is most frequently laid from four to six in the afternoon; the mean time is 5:10 P. M.

3. Egg B is usually laid early in the afternoon, most frequently between one and two o'clock, but may be laid as early as 8 to 9 A. M., and as late as 3 to 4 P. M.

4. The mean time of laying of egg B is 1:22 P. M.

5. The mean time between the laying of eggs A and B is accordingly 44.21 hours, or 44 hours, 12 minutes.

6. From the shape of the curves it might be inferred that there is somewhat greater variability in the time of laying of A than of B, although the range of the latter is slightly greater. A comparison of the standard deviations in the two cases, however, shows no significant difference. These are: for A, 1.008 ± 0.048 hours; for B, 1.002 ± 0.048 hours.

As stated above, the mean time intervening between the laying of eggs A and B is 44 hours and 12 minutes; the extremes are 42 hours on the one hand and 47 hours on the other. The distribution of frequencies with respect to interval between layings is shown in Figure 3. The variability of this interval as measured by the

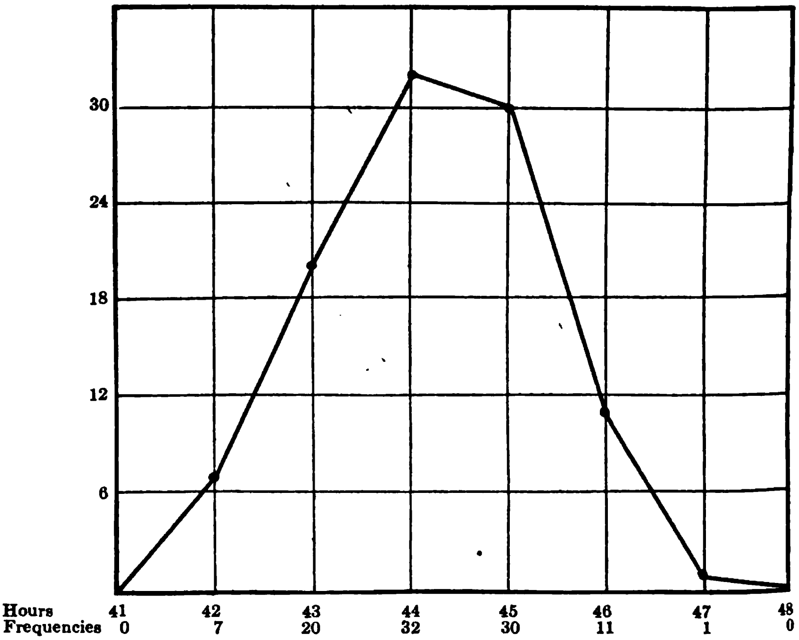


FIG. 3. Curve showing interval in hours between laying of first and second eggs in 101 sets.

standard deviation is slightly, though scarcely significantly, greater than the variability in the times of laying of A and B respectively ($\sigma = 1.120 \pm 0.079$).

TABLE IV.—*Interval between laying of eggs A and B arranged by months. (Includes 89 records made in 1898.)*

MONTH.	Hours between laying of A and B.						Total.	Mean.
	42	43	44	45	46	47		
January	....	....	....	1	....	....	1	45.00
February	....	....	1	4	3	1	9	45.44
March	1	2	4	5	4	....	16	44.56
April	....	4	8	7	3	....	22	44.41
May	....	4	4	9	1	....	18	44.39
June	1	5	6	1	....	....	13	43.54
July	2	2	6	....	....	....	10	43.40
Total	4	17	29	27	11	1	89	44.30

Perhaps the most interesting fact with respect to the interval between the laying of A and B comes out when the records are considered by months, as is done in Table IV. The 12 records of 1907, which were scattered throughout the year, are not included in this table. A comparison of the means for the different months shows that with the exception of January, for which there was but a single record, and which may therefore be disregarded, the mean time between the laying of A and B decreases perceptibly for each month from February to July. This fact is shown more graphically in Figure 4, where the means are plotted with their values as ordinates and the months as abscissæ. The straight line which best fits these observations has the equation $y = 46.02 - 0.385x$, where y is the interval between the eggs in hours and x the month of the year from February to July, inclusive.

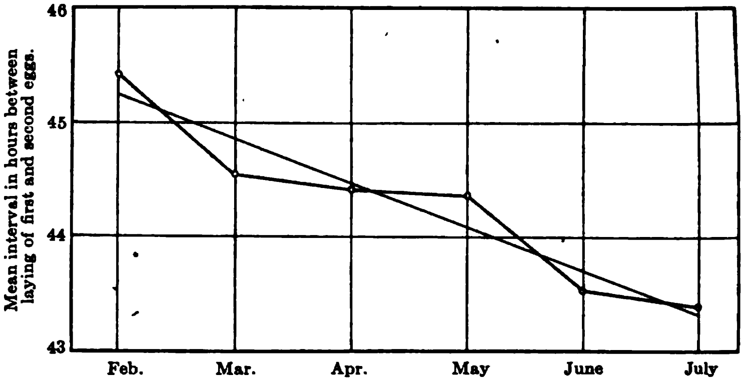


FIG. 4. Decrease in monthly mean interval between laying of the two eggs of a set, from February to July, 1908, inclusive.

It is unfortunate that records were not obtained for the remaining months of the year so that we might know whether the interval would continue to decrease or whether it would shorten again as the season progressed. The latter seems the more probable assumption, but in the absence of further records there is nothing to test it. Two possible explanations suggest themselves to account for the progressive shortening of the mean interval between laying of A and B from February to July. In the first place it is possible that this change is simply a reaction to temperature conditions, the physiological processes of the bird being accelerated and the interval correspondingly shortened in response to the warmer weather as the season advances. It seems rather more probable, however, that the physiological change in ovulating activity is directly related to the normal cycle of egg production in the pigeon. In domesticated pigeons the cycle of egg production undoubtedly extends over a longer period than it does in the wild state, as is the case also in the domestic fowl. Whether, in pigeons, this is a result of selection, direct or indirect, we do not know. At any rate the normal season of egg production may be assumed as in the spring or early summer. With the extension of the season we might expect the highest activity of the physiological processes of egg production to occur at the normal season, and a lessened activity at the beginning of the season, leading up to the maximum.

If a female which laid one of the earliest A-eggs (1-2 P. M.) had laid the second egg among the latest of those recorded (3-4 P. M.) the interval would have been 50 hours; on the other hand the shortest possible interval (A, 6-7 P. M.; B, 8-9 A. M.) by the same method of calculation would have been 38 hours. As a matter of fact we have seen (Fig. 3) that the shortest interval between the laying of A and B was 42 hours and the longest 47 hours. This suggests a distinct positive correlation between the time of laying of A and B, and in Table V the data are displayed in the form of a correlation table.

TABLE V.—*Correlation between times of laying of first and second eggs.*

	Time of laying second egg.								
Time of laying of first egg.	7:30– 8:30.	8:30– 9:30.	9:30–10:30.	10:30–11:30.	11:30–12:30.	12:30– 1:30.	1:30– 2:30.	2:30– 3:30.	Totals.
12:30—1:30	....	....	1	....	....	....	....	....	1
1:30—2:30	1	....	....	....	....	....	....	....	1
2:30—3:30	....	....	....	1	3	3	1	....	8
3:30—4:30	....	....	....	1	8	20	5	....	34
4:30—5:30	....	....	....	1	9	15	6	3	34
5:30—6:30	....	....	....	....	5	10	8	....	23
Totals	1	0	1	3	25	48	20	3	101

The distribution of the records in the table indicates some correlation, and the calculated coefficient gives $r = + 0.38 \pm 0.057$, which is a very sensible correlation. The equation to the regression straight line is $y = - 0.48 + 0.378x$, where x is the time P. M. of laying of the first egg, and y that of the second. By substituting in the formula the time that any given first egg is laid, the value of y gives the most probable time of laying of the second egg. This formula is based on all the available data, and is not corrected for the different months.

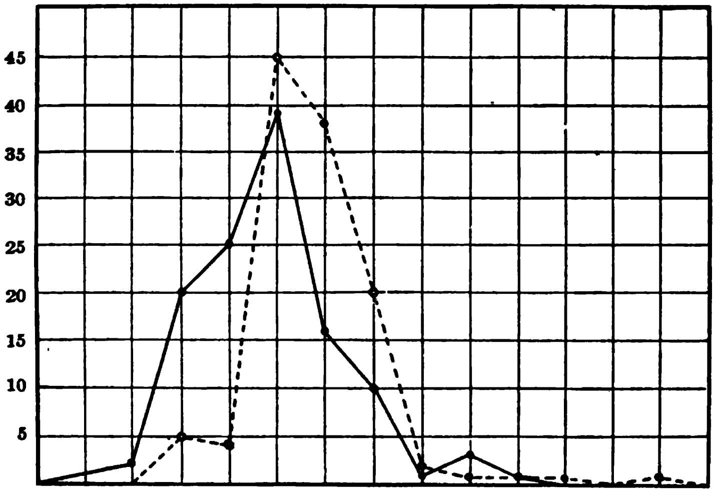
For convenience of reference the more important constants which have been developed in the foregoing section are here brought together.

Mean time of laying of A	5:10 P. M.
Mean time of laying of B (on second day following A)	1:22 P. M.
Standard deviation of time of laying of A	1.008 ± 0.048 hours.
Standard deviation of time of laying of B	1.002 ± 0.048 hours.
Mean interval between laying of A and B	44.21 hours.
Standard deviation of same	1.120 ± 0.079 hours.
Coefficient of correlation of laying of A and B	0.38 ± 0.057.
Regression straight line of same	$y = -0.48 + 0.378x$.

Time of Hatching of Eggs A and B.

Aristotle (1910, $562^{b}30$) gives the period of incubation of the pigeon as only 14 days, but it would seem as if he must here be referring to one of the smaller species, such as the Turtle Dove. Moore (1735, p. 11) in his famous "Columbarium" says: "The time of a pigeon's incubation, which trouble is equally divided between the cock and hen, except that the hen always sits all night, is nineteen or twenty days from the first egg, and seventeen or eighteen from the last," with which statement, as regards the period of incubation, modern authorities are in accord.

Our books at the present time contain several thousand records of the day of laying and the day of hatching of eggs, taken in the course of the regular daily routine. Since, however, the recording has not always been done at the same time of day, the period of accuracy may in reality sometimes be longer than a 24-hour period, as for example would be the case if the records were taken in the forenoon of one day, and not again until the afternoon of the day following. We have, however, 118 records in which the time of hatching of both eggs is known within a 12-hour period; for those which hatched in the daytime the time of incubation of the egg is indeed often known within an hour or two, but for the night we seldom known the actual time of hatching closer than that it occurred between 6 or 8 P. M. and 8 A. M. It seems best therefore simply to group the hatchings into half-day classes, the one including the daytime period from 8 A. M. to 8 P. M., the other the nighttime from 8 P. M. to 8 o'clock the following morning.* By this method an egg hatching between 8 o'clock in the morning and 8 o'clock in the evening of the seventeenth day after the laying of egg B would be put in class "17;" if it was not hatched by 8 P. M., but was found out of the shell at 8 o'clock the next morning (that is, on the eighteenth day) it would be put into the "17.5" class. As has already been stated (p. 486) one of the eggs was often put into the incubator a short time before hatching, and hatched there, but there is no reason to believe that this has had an appreciable effect on the results.



Days.	14.5	15	15.5	16	16.5	17	17.5	18	18.5	19	19.5	20	20.5
A-egg.	1	2	20	25	39	16	10	1	3	1			
B-egg.			5	4	45	38	20	2	1	1	1	0	1

FIG. 5. Curves showing the time of hatching of the first and second eggs, in days after the laying of the second egg. Solid line, first egg; dotted line, second egg.

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*As a matter of fact observations in many cases were not made after 6 P. M. Tabulations on this basis and on the 8 to 8 basis, show however practically no difference so far as our records indicate and it has accordingly seemed best to make the two classes of equal length. It should be remembered, however, that in an unknown proportion of the cases the night period is in reality longer than the day period. This may account in part for the larger number of recorded hatchings at night (see p. 497).

The distribution of frequencies with respect to time of hatching of both eggs is shown in Figure 5, the unbroken line connecting the records for the A-egg and the broken line those for B. The point of greatest interest which immediately impresses one on examining this figure is the remarkable extent to which the two polygons overlap, considering that there is a mean difference of slightly more than 44 hours between the times of laying of the eggs whose hatchings are represented by the two polygons respectively. This fact is further brought out by considering the mean times of hatching of A and B, which, based on the 118 records for each, are 16.42 days for A and 16.89 days for B, the time being reckoned in each case from the day on which B was laid.* In other words, we may say for practical purposes that although there is a mean difference of nearly two days in the laying of A and B, on the average A hatches 18.5 days after it is laid (16.5 days after B) and B hatches 17 days after its is laid.

TABLE VI.—*Correlation between hatching of first and second eggs.*

Hatching of first egg in days after laying of second.	Hatching of second egg in days after it was laid.											Totals.
	15½	16	16½	17	17½	18	18½	19	19½	20	20½	
14½	1	....	....	....	....	....	....	....	....	....	....	1
15	1	....	1	....	....	....	....	....	....	....	....	2
15½	2	2	14	2	....	....	....	....	....	....	....	20
16	....	1	13	8	3	....	....	....	....	....	....	25
16½	1	....	17	19	2	....	....	....	....	....	....	39
17	....	1	....	6	8	1	....	....	....	....	....	16
17½	....	....	....	3	5	1	....	1	....	....	....	10
18	....	....	....	....	1	....	....	....	....	....	....	1
18½	....	....	....	....	1	....	1	....	....	....	1	3
19	....	....	....	....	....	....	....	....	1	....	....	1
Totals....	5	4	45	38	20	2	1	1	1	0	1	118

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*In addition to the 118 records used above there are 13 in which the time of hatching of A is known, but not that of B, and in 18 cases the time of hatching of B alone is recorded. If these are included the mean for A is not changed, but that for B becomes 16.91.

Furthermore, a high degree of correlation exists between the time of hatching of the two eggs of a set. The data are arranged in the usual fashion in Table VI, and the calculated coefficient gives a correlation of + 0.728 ± 0.029. The class interval used—i. e., 12 hours—is rather wide, and it is probable that the apparent correlation has been exaggerated somewhat for this reason; that there has, however, been no sensible selection of the data by choosing day and night periods is indicated by a comparison of the means already given with those obtained when the records are treated separately for these periods as is done in Table VII.

TABLE VII.—*Mean time of hatching of eggs A and B after laying of B.*

	EGG A.		EGG B.	
	Number of records.	Mean	Number of records.	Mean.
All records combined....	118	16.42 ± 0.05	118	16.89 ± 0.04
Day hatchings (8 A. M.–8 P. M.)...........	45	16.42 ± 0.07	45	17.00 ± 0.05
Night hatchings (8 P.M.—8 A. M.)...........	73	16.42 ± 0.06	73	16.82 ± 0.05

Although there are in both cases more eggs hatched in the night period than in the day* (the numbers happen to be the same for both A and B), the mean is unchanged for A, and in B the difference is not great enough to affect the results of the correlation seriously. We are justified in concluding, therefore, that not only is the mean interval between hatching of all the A eggs as compared with B a half day, but that for any particular set of two eggs there is a strong probability that B will hatch in the next half-day following the hatching of A. The proportion of cases in which A and B hatch in the same half-day is less than half the number of cases in which A hatches before B; in only a small proportion of cases does B hatch before A. The actual numbers are as follows:

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*This may perhaps be accounted for in part by the fact that sometimes the last day records were made at 6 P. M., instead of 8 P. M. (see footnote, p. 495). This does not seem sufficient to account for the entire difference, but we have at present no other explanation to offer for the excess of night hatchings.

	Number of cases.	Proportion of total.
A hatched before B	79	67%
A hatched same half-day as B	32	27%
B hatched before A	7	6%
Total	118	100%

Attention has already been called to the longer period of incubation of A than of B. Leaving out the fractions, A is laid on the average 44 hours before B, but hatches on the average only 11 hours before B. The difference—33 hours, or almost a day and a half—is the mean time by which the incubation period of A exceeds that of B. Two possible explanations of this difference between A and B in the time from laying to hatching suggest themselves: (1) Egg A may be physiologically different from B and require a greater amount of incubation, or (2) although there is a longer interval between the deposition and hatching of A the birds may not sit on it so closely when it is first laid, so that it may really receive no more incubation than B. The first of these suppositions is a very unlikely one from a biological standpoint, for while the possibility of an intrinsic difference between A and B which might influence the time required for incubation, such as gross size, relation of size of yolk to amount of white, or what not, cannot be denied, there are no data to indicate such a relation. As for the second explanation, there are direct observations in support of it. Nearly every writer on pigeons states that the birds do not incubate the first egg, but stand over it until the second is laid, when incubation properly begins. Thus going back to Moore (1735, p. 11) again, we find him stating that "When a

Pigeon has laid her first Egg, she rests one Day between, and on the succeeding Day lays her second: They generally stand over the first Egg, which if you please, you may call an improper Incubation, till the next is laid, and then sit close, that both young ones may be hatch'd at once, or pretty nearly; tho' some will sit close on the first, and by that means hatch one young one two Days before the other." Mr. Kelley states that from his observations he is of the opinion that whereas the hen stands over the first egg in this manner, the cock, when he is on the nest, sits much closer and thus the egg receives some incubation before B is laid. This partial incubation probably accounts for the half-day which A hatches on the average ahead of B. That this is the case is further indicated by the fact that by candling the eggs a day or so after the laying of B the embryo may usually be seen to be in a further stage of development in A than in B, its greater development evidently representing the incubating it has received before B was laid.

Even though we may not be willing to accept the teleological explanation of Moore for the behavior of the female in not incubating the first egg, we must admit nevertheless that it has important biological significance. It is a well established fact for other birds as well as for pigeons that the parents use no judgment in feeding the young, but always fill up first the youngster which is most insistent. In this way it is the most active and vigorous individual which is first satisfied with food. While this may tend toward the survival of the fittest in a brood, it is also an example of failure in biological regulation. It would seem as if it were better, so long as the food supply was sufficient, for the parents' instincts to lead them to feed first the retarded individuals, and thus give all in the brood an equal chance. However this may be, every pigeon raiser knows that where there is much difference in size between the two squabs in a nest, the smaller rarely has much chance of survival unless it is given special attention and care. Disadvantageous difference in size is very frequent in pigeons, and it is our practice to exchange squabs (marked, of course, for identification) in nests of this sort, so as to bring together those more nearly of a size and thus having more nearly equal opportunities. In this way we undoubtedly save many birds which would otherwise die of starvation or be crowded from the nest by their more fortunate nestmates.

From the foregoing we may conclude then that in all probability the time required for incubation by the two eggs is the same, but although A is laid nearly two full days before B, it receives on the average the equivalent of only about a half-day of incubation before B is laid, so that its mean time of hatching is only a half-day before that of B. From the standpoint of the welfare of the second squab it would probably be better if this interval were still shorter, so that the eggs should hatch essentially at the same time. To this extent the instinct which allows A to be incubated at all in advance of B is imperfect. On the other hand, domesticated birds at any rate often breed during such cold weather that the first egg would freeze if it were not protected at all.

"Control of Sex" in Pigeons.

Practically all of the various factors which have been held by the poultryman to determine sex in poultry, have been put forward for pigeons as well. These include such things as size and shape of egg, position and size of the air space, and the like. Such theories in the past have admittedly had no adequate experimental basis, nor have facts in their support been adduced which could stand the test of scientific proof. More recently, however, certain assertions have been made by Riddle as to the control of sex in pigeons, but the data on which these statements rest have not as yet been published so far as we are aware. Riddle (1914) states definitely and categorically, however, that "By his method of controlling sex in pigeons Whitman showed (1) that the first young of the season (spring and early summer) were nearly all males, and young hatched from the later eggs of the season were nearly all females; (2) that if the two sexes arise from the two eggs of any one clutch, that it is in nearly all cases the first egg which produces the male, and the second egg of the clutch that produces a female; (3) that birds kept thus mated and overworked at egg-production tend to produce in succeeding years fewer and fewer males before the appearance of females."

Since Professor Whitman's records and notes have never yet been published, but are, we understand, being edited for that purpose by Dr. Riddle, we do not deem it advisable to enter into an extended discussion of these points at this time. Attention should however, be directed again to the fact that Cuénot's results and our own, which combined are of considerable magnitude, are directly contradictory to the second of Riddle's assertions. Furthermore, if his other contentions are true, it is surprising how they are masked when the statistics are treated in their entirety—it seems, indeed, very improbable that the distribution of sexes would balance up so as to give such a decided indication of being chance results as has been shown to be the case in the present report. More attention will be given to this matter in a subsequent paper, in which the data will be considered with respect to the different seasons and conditions.

As one of us has pointed out elsewhere (Cole, 1913) ideas of sex determination are often confused by the pigeon breeder with misunderstood facts of sex-linked inheritance which come up in the course of his breeding operations. Because, for example, he finds that in certain of his matings a large proportion, amounting in some cases to 100 per cent., of the dilute colored offspring (dun, silver or yellow) are females, he concludes that in some way sex is being determined other than by chance. He does not realize that instead of controlling sex he is simply able in certain cases to tell the sex of an individual by its color. In this connection, simply by way of example, a paper by Martin (1912), entitled "How to control the sex of pigeons," may be mentioned.

Length of Time Pigeons will Incubate when Eggs do not Hatch.

It has been claimed by Raspial (1897, 1907) that Turtle doves and pigeons have a very nice adjustment to the normal period of incubation of the eggs, and that if these do not hatch at the proper time the parents will abandon them at once. In his earlier paper he reports the case of a female Turtle dove ["Tourterelle vulgaire (*Turtur auritus*)"] which twice had infertile eggs and abandoned them on the eighteenth day. He argues that since "about 18 days," is the period of incubation of the domestic pigeon, it is probably the same in all of the Columbidae, and this case accordingly proves that the dove "had a very exact notion of the period of incubation and the futility of sitting longer"! As a matter of fact the period of incubation of the Ring dove (*Turtur risorius*) is only about 15 days, and it is probably shorter in all the smaller doves than in the pigeon.

In the second paper he refers again to the Turtle dove and adds the case of a homing pigeon which four times abandoned its eggs on the eighteenth day, the eggs in each case being infertile. He says it is then the knowledge by the female pigeon [Why the female alone, since both sexes take part in incubation?] of the time that should elapse for the eggs to hatch, that enables her to abandon them when they are infertile. Considering the extreme delicacy of the sense which Raspial claims to have shown "enables the Turtle dove to perceive when a profane hand has, during her absence, touched her eggs or young, and which leads to her abandoning them without pity," it is to him "astonishing that she has not the faculty of recognizing sooner that the life is not developed in so intimate a product of her generative organs, and that it is necessary for the whole period of incubation to elapse for her to comprehend the inutility of her efforts." He is furthermore surprised to find this phenomenon in birds of the same family, but living under such different conditions, the one in captivity, the other free. He points out that in contrast to pigeons the domestic fowl has lost this "notion of the time of incubation," and "will frequently incubate infertile eggs until completely exhausted, if no one takes the trouble to stop her."

Anyone who has had even a little experience raising pigeons well knows that Raspial's generalization with regard to their always abandoning their eggs on the eighteenth day in case they do not hatch is unfounded and unjustified. Wright (1879, p. 40) observes incidentally on this point: "We have *occasionally* kept birds we desired as feeders as much as seven days *on eggs* (in one case eleven days) beyond the proper time of hatching, and then given them young ones only two days old."

Even before we knew of Raspial's papers we had begun the collection of records relating to the time the birds would continue to incubate the eggs in case they did not hatch. Most of the records were made from sets in which the eggs were sterile or in which the embryos died, but in a few cases the eggs were boiled to prevent their hatching, in order that more data on this point might be obtained. In some cases one of the eggs became broken or was otherwise lost during the course of the incubating process; it was then either replaced by a sterile "dummy" egg, or the birds were allowed to continue with the one egg only. In one or two instances one egg hatched, but the squab dying very soon the birds continued incubating the other. Although the records thus represent a variety of conditions, they are all cases in which the birds had incubated normally the full 17 days, and there therefore seems to be sufficient uniformity in the conditions influencing their behavior to allow of their all being treated together as is done in Table VIII. From the footnotes appended to the table it is seen that certain factors, such, for example, as the cases in which no second egg was laid, which might be conceived to have an influence on the time of sitting, are distributed through the records with impartial uniformity.

The 59 matings included in the table are all for the earlier years of our work (1908-1910); since that time the change of method in using foster parents for raising the young of selected parents and the forcing of the birds to their greatest capacity has not been consistent with obtaining data on the point at issue. We still, however, allow the birds to incubate a day or two beyond the normal period unless it is certain that the embryos are dead, so that from our routine experience together with the data in Table VIII, we are able to state positively that it is very infrequently that the birds cease incubating voluntarily by the eighteenth day after the laying of egg B, in case they are allowed to retain unhatched eggs. An inspection of the Table shows, as a matter of fact, that under the conditions specified more birds stop incubating at 23 days than at any other time, and that the number of records falls off from this point in both directions as regularly as could be expected with such small numbers. The

TABLE VIII.—*Length of time eggs were incubated when they did not hatch: counted from time of laying of second egg.*

(The numbers are those of the nestings concerned; each number represents one record.)

	Days	17	18	19	20	21	22	23	24	25	26	27	28
Number of records.	11	.....	.....	.....	.....	.....	.....	755†	.....	.....	.....	.....	.....
	10	.....	.....	.....	.....	.....	.....	688†	.....	.....	.....	.....	.....
	9	.....	.....	.....	.....	.....	.....	558	.....	.....	.....	.....	.....
	8	.....	.....	.....	.....	.....	.....	529	.....	737||	.....	.....	.....
	7	.....	.....	.....	.....	746	.....	512	.....	716	.....	.....	.....
	6	.....	.....	.....	.....	704	741	505	.....	533	.....	.....	.....
	5	.....	.....	.....	.....	445	653	494*	695	464	729	.....	.....
	4	.....	757	.....	.....	425	402‡	475	595†	357	675	.....	.....
	3	605§	477	761	.....	422	400†	426	498	330	674	714	.....
	2	470*†	476	551	386	379†	335	267	309	316	406	703	465
	1	308	305	541†	332*	241	298	180	280	304	384†	381	331†
Totals		3	4	3	2	7	6	11	5	8	5	3	2

*Record incomplete.

†Only one egg laid; calculation made from time second egg should have been laid.

‡One squab hatched, but died soon.

§Adopted squabs from another nest.

||Possibly a day or so less.

maximum time any birds sat was 28 days,* whereas the mean period which they will sit on the eggs in case they do not hatch, as determined from these 59 records, is 22.69 days. There is therefore a tendency for domestic pigeons, as represented by this group, to incubate the eggs not simply to the mean (17 days), nor indeed to the maximum (20.5 days) time of hatching, but for a somewhat longer period, the average being practically 23 days. The incubating instinct is not, therefore, one exactly adjusted to the number of days required for the young to hatch—such an exact adjustment would in fact be out of the question owing to the considerable variability of this period—but there is rather, as in many instincts and other biological adjustments, a *factor of safety*. Physiological processes in general are characterized by variability, and nature, rather than drawing the line too closely, makes allowance for the extremes. In the present instance the factor of safety may be considered as 6 days, the difference between the mean time of hatching of the second egg and the average time the birds tend to sit. This is fully two days longer than necessary to hatch the eggs which required the longest time (20.5 days) according to our records, and if we may generalize from our data, fully 68% of the birds sit long enough to hatch even the few eggs that reach this limit.

The foregoing data would appear to show conclusively that Raspial was wrong in attributing to the domestic pigeon an exact "notion of the time necessary for incubation" or anything comparable to it. For some years the senior author has desired to test the matter on a wild species, but has had little opportunity to do so. In the spring of 1914, however, with the assistance of Mr. A. R. Cahn, a complete record was made of the laying and incubation of a pair of Mourning Doves (*Zenaidura macroura carolinensis*). The nest was some 12 or 15 feet from the ground on the horizontal branch of a tamarack tree on the campus of the University of Wisconsin. The chronological history of the case is as follows:

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*The statement of a maximum of 30 days in a preliminary communication (Cole, 1911) was based on the time of laying of the first egg rather than the second.

May 4, 1914. A pair of Mourning Doves observed "looking over the location;" their behavior indicated that they would probably nest soon.
May 7. Foundation of nest laid at place where birds were previously seen.
May 10. Nest apparently complete; no eggs; birds not in evidence.
May 12. First egg laid before 8 A. M. (no record of time of last observation on day previous).
May 13. Second egg laid between 8 and 9 A. M.
May 14. Birds incubating.
May 23. Two eggs with dead embryos of Ring dove (*Turtur risorius*) substituted for the Mourning Dove eggs; the latter placed in an incubator.
May 26. Mourning Dove eggs both hatched in incubator during night; period of incubation 13 days from laying of second egg.
May 28. Mourning Doves still incubating.
May 29, 1:30 P. M. Mourning Dove on nest.
May 30, 8:30 A. M. Mourning Dove on nest.
10:30 A. M. Nest deserted; birds not seen around it thereafter. Still contained the substituted eggs, thus showing it was not an accident to the eggs which caused the termination of incubation.

While this is but a single case, the evidence it furnishes is positive, and there is no reason to believe it is not about what might normally be expected under similar circumstances. The points of interest to us may be summed up briefly:

1. The period of incubation for both the Mourning Dove eggs was 13 days from the time of laying of the second egg.
2. The parent birds continued to sit on the substitute eggs for four days after their own eggs had hatched, which is 31 per cent. of the period of incubation of their own eggs. In the domestic pigeons the "factor of safety" was determined as 6 days, or 35 per cent. of the mean period of incubation.

It is interesting to note that desertion of the eggs by the Mourning Doves occurred after 8:30 in the morning and before 10:30. If their habits with respect to the division of labor in incubation are similar to those of pigeons, the male sitting approximately from 10 A. M. to 2 or 3 P. M., this probably means that it was the male bird which first failed to continue the extended incubation of the refractory eggs.

Summary.

Below are summarized the principal conclusions of the present report. Although some of them may here be stated in a rather general form, it is to be kept in mind that they are based wholly on the data which have been presented, and no claim is made for their generality beyond this. Nevertheless it is our *opinion* that they are built on a broad enough foundation to render very probable their general application to domestic pigeons.

Sex ratio.

1. The normal ratio of the sexes of pigeons hatched is 105 males to 100 females (p. 465).

Death rate.

2. The death rate of squabs is especially high for the first two or three days after hatching, and at about 10 to 15 days of age (p. 470).

Differential mortality.

3. When the two squabs are of distinctly different size before the banding age (10 to 15 days) the larger squab is more often a male than a female (p. 467).
4. The death rate for the two sexes, in bisexual broods, is essentially equal (p. 471).
5. There is no marked tendency for one sex to be weaker than the other in bisexual broods, and there is only a slight indication that more males than females from such broods survive to adult life—placed at 6 months (p. 472).
6. A consideration of the ratio of males to females in each of the age groups defined does not indicate a high relative mortality of females in the ages preceding the adult state (p. 473).
7. There is a high mortality of both sexes during the first two or three years of their adult life, and this is especially high in the females between the ages of one and two years (p. 476).

8. The higher mortality of females at early adult ages, together with the higher proportion of males hatched (105 : 100), may be in large part responsible for the prevailing notion of a considerable excess of male pigeons in adult populations and seems to furnish real substantiation for this notion. The fact that males are generally more easily recognized than females probably adds to this impression (p. 477).

Ratio of bisexual to unisexual broods.

9. The number of unisexual broods, in which the squabs are either both male or both female, somewhat exceeds in our records the bisexual broods (one squab of each sex), but the odds against the numbers obtained representing a potential equality are very slight. These facts are directly contradictory to the statements that the two eggs usually produce a male and a female squab (p. 487).

10. Considering only the unisexual broods, the number of "both males" to "both females" is practically equal (p. 487).

Sex with respect to order of laying.

11. A comparison of the numbers of each sex hatched from first eggs and from second eggs respectively, shows no tendency for the former to produce exclusively males and the later females, but as a matter of fact more males than females are hatched from both (p. 487).

Time of laying.

12. The mean time of laying of the first egg is about 5 P. M., and of the second egg about one o'clock of the afternoon of the second day following (p. 489).

13. The mean interval between the laying of the two eggs is practically 44 hours (p. 490).

14. The mean time between the laying of the first and second eggs decreases progressively in the months from February to July, inclusive (p. 491).

15. There is a very sensible positive correlation between the time of laying of the first and of the second egg. The equation of the regression curve is given, which enables one to calculate the most probable time of laying of the second egg when the time the first was laid is known (p. 493).

Time of hatching.

16. The mean time of hatching of the first egg is 16.5 days after the laying of the second (p. 496).

17. The mean time of hatching of the second egg is 17 days after it is laid (p. 496).

18. On the average, therefore, the time from laying to hatching of the first egg is nearly a day and a half longer than it is for the second egg. This is probably to be accounted for by the fact that the first egg receives very little incubation until the second is laid (p. 499).

19. There is a high correlation between the times of hatching of the two eggs of a clutch (p. 497).

"Control of sex."

20. So far as the data presented go, they appear to indicate that sex in pigeons is determined according to the laws of chance (p. 501).

Time of sitting.

21. In case the eggs do not hatch they are seldom abandoned at the end of the normal period of incubation, but the birds continue to sit on them for a time longer (p. 504).

22. The length of time they will continue to incubate the eggs varies, but averages practically six days after the normal period, making the mean total time of incubation when the eggs do not hatch 23 days after the laying of the second egg (p. 504).

23. This continuance of incubation beyond the normal time under such circumstances constitutes a "factor of safety" in the incubating instinct (p. 505).

24. A pair of Mourning Doves continued to sit on substituted eggs for four days after their own had hatched in an incubator, thus disproving Raspial's assertion that wild birds have an "exact notion of the time required for the eggs to hatch" (p. 506).

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THE COMPARATIVE VALUE OF DIFFERENT SOURCES OF PHOSPHORUS.

BULLETIN 163

Agricultural Experiment Station

OF THE

Rhode Island State College

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AGRICULTURAL EXPERIMENT STATION OF THE RHODE ISLAND STATE COLLEGE.

BULLETIN 163, JUNE, 1915.

THE COMPARATIVE VALUE OF DIFFERENT SOURCES OF PHOSPHORUS.*

BURT L. HARTWELL AND S. C. DAMON.

Introduction.

This bulletin treats of the field experiments on soil of the same general character, which have been conducted at the station plain, during the years 1894 to 1913, to compare different phosphatic materials. Reference is given to such of the data as have been published earlier in the station bulletins and reports, but in order that the reader may be acquainted easily with the main facts, even the published material is summarized briefly. This course is made especially desirable by the fact that most of the earlier publications are out of print.

Three experiments are involved. No part of the first two included herein has been published heretofore. They were conducted under the supervision of the former director, H. J. Wheeler. Experiment I was undertaken for the purpose of determining whether the fertilizer ingredients of guano, as a whole, differed materially in agricultural value from the same amount of ingredients in bone, nitrate of soda, acid phosphate and muriate of potash. Although the applications were based upon the phosphorus content of the materials, the experiment should not be considered as furnishing definite information regarding the relative availability of any single ingredient. The second experiment was planned to ascertain the availability of only the phosphorus, but during the seven years' continuance of the experiment, the soil itself yielded so much phosphorus that the influence of the phosphates was not conclusive.

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*Contribution 216 from the Agricultural Experiment Station of the Rhode Island State College.

The third experiment* has been conducted during sufficient time to afford quite definite information regarding the availability of phosphorus in nine different sources and its presentation comprises most of this bulletin. The period not covered by previous publications extends from 1905 to 1913 and represents especially the aftereffect exerted by the different phosphates which had been applied since the beginning of the experiment in 1894. Since 1913 certain modifications have been adopted, and applications of such phosphates as have been retained have been begun again.

Owing to the recent changes in the plan, the first twenty years of the experiment have been considered as completing certain of its phases and are treated somewhat as a unit in the final discussion.

Experiment I. A Comparison of Guanos, Ground Bone and Dissolved Phosphate Rock.

Enough of these materials was applied to the land to furnish equal amounts of phosphorus. They were supplemented with sufficient nitrate of soda and muriate of potash so that there was added also an equal amount of nitrogen and potassium. Except in 1910, the guanos were not supplemented.

The experiment was conducted from 1905 to 1910 on four of the permanent plats of the station, Nos. 42, 45, 47 and 48. Although the four plats had not been cropped alike previously and were therefore not strictly comparable, the entire area of each individual plat had been treated alike. Each plat was therefore divided into four equal parts by crosswise paths, the three phosphatic materials were added respectively to three of the sections; and the fourth section, which was not in every case on a level with the others, was left without any manurial additions.

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*Until recently this experiment was mainly under the general direction of C. O. Flagg and H. J. Wheeler, former directors and agronomists of the station, aided in the field work principally by Messrs. Towar, Tucker, Tillinghast, Adams and Damon as assistants in agronomy.

The guano used on sections of plats 42 and 48 was more nitrogenous and less phosphatic than that used on sections of plats 45 and 47, as may be seen by the following percentage analyses:

	Analvses of guano applied to 42 and 48.		Analyses of guano applied to 45 and 47.	
	1905.	*1906–10.*	*1905.*	*1906–10.*
Nitrogen	9.27	7.76	2.77	3.02
Phosphoric acid	10.58	9.56	22.42	19.71
Potassium oxid	2.29	2.21	3.57	4.08

"Chincha" was the commercial name of the more nitrogenous of the guanos used from 1906–10 and "Lobos" of the less nitrogenous one.

The application of phosphoric acid (phosphorus pentoxid) was 40 pounds per acre in 1905 and 20 pounds in 1906–10, for all plats and sections which received phosphorus, regardless of the source. The annual fertilizer applications to all manured sections were as follows:

	Pounds per acre applied to 42 and 48.			Pounds per acre applied to 45 and 47.		
	1905.	*1906–9.*	*1910.*	*1905.*	*1906–9.*	*1910.*
Phosphoric acid	40.00	20.00	20.00	40.00	20.00	20.00
Nitrogen	35.05	16.22	63.00	4.94	3.06	63.00
Potassium oxid	8.66	4.62	150.00	6.37	4.13	150.00

In the spring of 1910, 3,780 pounds of air-slaked lime to the acre were added to the entire area. Previous to this there had been none added except to plat 42, which received an application of 1,500 pounds to the acre in 1897. One ton of wood ashes per acre was applied, however, to plats 47 and 48 in 1898. The soil must have been too acid during most of the experiment for the best growth of certain of the plants.

The area of each section, exclusive of the dividing paths was .0310 acre, and the weights of the crops for each year are given for that area in Tables I and II.

In 1905 purple-top flat turnips were grown; and for a second crop eclipse table beets were planted, but these failed; perhaps because the soil was too acid. In 1906 flat turnips were again grown for the first crop, followed by ruta-bagas as the second crop. In 1907 the land was seeded to oats and a mixture of timothy, redtop, red and alsike clover; more of the same mixture was sown in the following spring and the land left in grass for two years. In 1910 a crop of white rock Swedish turnips was secured from the west half of each section and long orange carrots from the east half; the yields of each of these two crops are given in the tables, for .0155 acre.

The yields for a given year which are strictly comparable are only those of the different sections of a given plat, for the preceding history of the different plats was not uniform. With the exception of the last year of the experiment, when the applications of nitrogen and potassium were sufficiently liberal so that the crop yields were probably determined by the amount of available phosphorus, it is impossible to know which fertilizer ingredient was most deficient, for it may have been noticed that the applications were small in each case, the nitrogen and potassium being limited to the amounts contained in the guanos.

Referring to the yields given in Table I, it may be seen that from plat 42 without exception as large or larger crops were secured each year from fine ground bone than from either Chincha guano or dissolved phosphate rock (acid phosphate), the total yield being 2,546 pounds, whereas the yields with the latter two were about equal, averaging 2,163 pounds. From plat 48, the largest total yield, 2,500 pounds, was secured with Chincha guano, because the turnips in the first and last year of the experiment yielded best on this section; with all other crops larger yields were secured from the bone than from the guano, the total being 2,435 pounds for the bone. The total yield with the dissolved phosphate rock and the accompanying ingredients, was less, being 2,357 pounds.

By reference to Table II it may be seen that no one of the special fertilizer treatments is superior to the others on both plats. Again

TABLE I.—*Pounds of crops grown on each .0310 acre section.*

	SECTIONS.	PLAT 42.				PLAT 48.			
		I. Bone.	II. Chincha guano.	III. Dissolved phosphate rock.	IV. Nothing.	I. Bone.	II. Chincha guano.	III. Dissolved phosphate rock.	IV. Nothing.
Year.	*Crop.*								
1905	Turnips, flat	785	705	785	688	845	950	895	645
1906	Turnips, flat	194	147	161	131	253	232	212	127
	Turnips, ruta-baga (second crop)	156	145	124	216	130	118	104	77
1907	Oat hay	117	86	97	104	110	109	108	98
1908	Hay	86	50	83	89	107	96	100	100
1909	Hay	147	93	126	105	107	99	109	126
1910	Turnips, Swedish	558	496	447	380	465	492	436	345
	Carrots, Long Orange	503	445	335	321	418	404	393	289
	Total	2,546	2,167	2,158	2,034	2,435	2,500	2,357	1,807

TABLE II.—*Pounds of crops grown on each .0310 acre section.*

	SECTIONS.	PLAT 45.				PLAT 47.			
		I. Bone.	II. Lobos guano.	III. Dissolved phosphate rock.	IV. Nothing.	I. Bone.	II Lobos guano.	III. Dissolved phosphate rock.	IV. Nothing.
Year.	*Crop.*								
1905	Turnips, flat	695	755	735	545	575	615	580	430
1906	Turnips, flat	185	169	143	109	150	136	155	121
	Turnips, ruta-baga	147	125	103	42	179	84	63	73
1907	Oat hay	84	92	67	97	73	95	115	87
1908	Hay	41	35	26	87	55	36	40	34
1909	Hay	92	93	75	88	73	48	63	54
1910	Turnips, Swedish	422	425	412	391	504	513	523	394
	Carrots, Long Orange	412	441	424	366	426	418	381	365
	Total	2,078	2,135	1,985	1,725	2,035	1,945	1,920	1,558

the total yields from the dissolved phosphate rock sections are less than from the others. The total yield from the ground bone section was less than from the Lobos guano section of plat 45, but in case of plat 47 the reverse was true.

By adding the total yields from the sections of all four plats which received similar fertilizers, it is found that the fine ground bone supplemented with sufficient nitrate of soda and muriate of potash to equalize the nitrogen and potassium in the guanos, yielded 9,094 pounds, as compared with 8,747 pounds from the guanos and with 8,420 pounds where dissolved phosphate rock, nitrate of soda and muriate of potash furnished nitrogen, phosphorus and potassium equal in amount to the content of the guanos.

The superiority of ground bone over dissolved phosphate rock on an acid soil is shown not only in this experiment but in the more extensive experiment which forms the latter part of this bulletin. In this connection attention is called to the phosphoric acid content of the moisture-free ruta-baga turnips grown in 1906.* The percentages in turnips from the four ground bone sections varied from .55 to .61, average .58; and from the acid phosphate sections, from .43 to .54, average .47. Phosphoric acid was determined also in the flat turnips of 1905, but from only plats 45 and 47; from the former the percentage in moisture-free turnips was 1.01 where the phosphorus was from bone and .93 where it was from dissolved phosphate rock: similarly from plat 47, the percentages were .91 and .83, respectively.

The foregoing percentages indicate that the phosphorus was more available in the ground bone than when supplied in dissolved phosphate rock. Possibly because the phosphorus in the latter entered into combination with iron and aluminum in the absence of calcium in alkaline combinations.

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*R. I. Agr. Expt. Sta. Bul. 154, pp. 123-4.

Experiment II. Thomas Slag Phosphate, Lobos Guano, Ground Bone and Dissolved Phosphate Rock Compared as Sources of Phosphorus.

This experiment was conducted on what was originally called Field B, but which now comprises permanent plats 126, 127 and 128, located just west of the barn on the station plain. The field was divided into four plats by crosswise paths six feet wide, extending east and west. After the first year of the experiment, when the special fertilizer of each plat was applied uniformly over its entire area, the plats were divided into sections *a* and *b*, the latter receiving no phosphates during the remainder of the experiment.

The entire area received each year 63 pounds of nitrogen and 150 pounds of potassium oxid per acre: on the *b* sections after the first year this was applied entirely in nitrate of soda and muriate of potash, whereas on the *a* sections these materials were used only in such quantities as were necessary to make up the stated amounts of nitrogen and potassium oxid after the different phosphates had been applied so as to furnish the amounts of phosphoric acid recorded in Table III along with the yields from the two sections of each plat. The yield from the whole plat during the first year was divided into two equal parts which were credited to sections *a* and *b* in the table.

In 1909 the slow growth of the early cabbages indicated that the soil was too sour for such kinds of plants, so 2,000 pounds of calcium oxid in slaked lime was mixed with the soil before setting out the late cabbage plants.

It may be seen by reference to the yields given in Table III that the initial fertility of the soil, together with the 55 pounds of phosphoric acid applied in 1904 supplied sufficient of this ingredient; for sections *b*, which subsequently received only nitrogen and potassium, yielded about as much of the hay occupying the land during the first five years of the experiment, as sections *a*, to which phosphorus was added each year. The same was true in certain instances even in subsequent years.

TABLE III.—*Application of phosphoric acid per acre, and pounds of crops from each section* (.03315 *acre*).

Year.		Phosphoric acid applied per acre, lbs.		PLAT I. Thomas Slag Phosphate.		PLAT II. Ground Bone.		PLAT III. Lobos Guano.		PLAT IV. Dissolved Phosphate Rock.	
		a	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*
1904	Mixed hay, lbs.	55	55	240	240	223	223	206	206	213	213
1905	Mixed hay, lbs.	40	0	201	238	188	165	171	177	159	182
1906	Mixed hay, lbs.	40	0	195	200	205	223	188	200	190	175
1907	Mixed hay, lbs.	40	0	230	205	225	220	240	250	220	220
1908	Mixed hay, lbs.	40	0	183	152	175	173	209	194	190	170
1908	Swedish turnips, lbs.	40	0	138	80	121	122	130	131	155	150
1909	Cabbages, early, lbs. heads	40	0	568	428	469	435	509	471	513	116
	other leaves			327	287	265	241	348	288	303	181
1909	Cabbages, late, lbs. heads	40	0	250	360	375	344	399	266	325	431
	other leaves			285	290	357	329	308	243	306	261
1910	Cabbages, early, lbs. heads	40	0	789	732	857	746	858	651	729	445
	other leaves			740	640	730	670	773	683	699	534
	Total	......	......	4,146	3,852	4,190	3,891	4,339	3,760	4,002	3,078

The slight deficiency of phosphorus in sections *b* where none was applied after the first year makes it impossible to draw conclusions regarding the availability of the phosphorus in the different sources. Otherwise this might have been done, since in this experiment, unlike the preceding one, liberal amounts of nitrogen and potassium were added in an attempt to make phosphorus the element which should control the growth.

A few comments on the total weight of crops may be justifiable, although at least most of the differences are certainly within the limit of experimental error, as the reader may see by referring to the table. It may be seen that with the exception of the one accompanying the dissolved phosphate rock plat the *b* sections, which received no phosphoric acid after the first year, produced about the same total amounts of crops. The excepted section, for some reason not appearing in the records, was so much less productive than the others that the increase over it, which was correlated with the addition of dissolved phosphate rock, was absolutely and percentagely greater than the increase caused by the other phosphates over the respective *b* sections. In spite of this, however, the total weight of crops was less from the dissolved phosphate rock section than from the other sections receiving phosphorus.

Experiment III. The Availability of the Phosphorus in Nine Different Phosphates Applied to Limed and Unlimed Land.

INTRODUCTION.

This experiment was begun in 1894 on the permanent plats numbered 51 to 70. The manures for a given plat have been applied uniformly over its area, and liberal equal amounts of nitrate of soda and potash salts added to all plats each year. The odd-numbered plats, 51 to 69, received equal applications of slaked lime in 1894, 1903 and 1911, whereas the even-numbered plats, 52 to 70, were left unlimed.

The relative position of the plats and the kinds of phosphate tested are shown by the following:

Unlimed plat.		Limed plat.
52	Dissolved Boneblack	51
54	Dissolved Bone	53
56	Dissolved Phosphate Rock	55
58	Fine Ground Bone	57
60	Thomas Slag Phosphate	59
62	Raw Phosphate Rock (Floats)	61
64	Raw Redonda Phosphate	63
66	Roasted Redonda Phosphate*	65
68	No Phosphate	67
70	Double Superphosphate	69

The plan of the experiment during the first five years was to apply to all plats receiving phosphate, amounts costing the same, but in 1899 the plan was changed so that all plats would eventually receive the same *amount* of phosphorus regardless of the cost.

After the applications of 1902 all the phosphate plats had finally received the same amount of phosphoric acid since the beginning of the experiment, namely: 738.6 pounds per acre, or an average of 82 pounds annually. From 1903 till 1913, inclusive, no phosphate was added to any of the plats, in order that there might be an opportunity for studying the after-effect of the various sources of phosphorus.

THE PERIOD FROM 1894 TO 1898, WHEN THE PHOSPHATES WERE APPLIED ON THE BASIS OF COST.

Corn was grown in 1894, oats in 1895, and hay in 1896, 1897 and 1898. The detailed accounts of most of this period may be found in earlier publications of the station;† but since these are no longer available for general distribution, and furthermore, because the results have never been summarized for these first five years in which the comparison of the phosphates was on an equal-cost basis, it seems best at this time to consider them somewhat more fully than will be the case with such later published results as are still available.*

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*An idea of the composition of Redonda phosphate is given by the following averaged determinations of two samples of the roasted material: aluminum oxid, 28.94; ferric oxid, 2.76; phosphorus pentoxid, 47.68 per cent.

†An. Rpt. (1894) 122-8; An. Rpt. (1896) 326-43; An. Rpt. (1897) 394-408; and Bull. 58 (1899).

In Table IV data are given concerning the phosphatic applications of the first five years. Although at the time of applying the different sources of phosphorus approximately the same amount of money was expended in each case, it was decided that it would be of more interest to the farmer of today in making plans for the future if current prices were adopted for the different phosphates, rather than those paid originally. In deciding upon these prices, which are given in the first column of the table, account was taken of the composition of the phosphates and of the prices of phosphoric acid in different forms, adopted recently by the northeastern experiment stations in connection with the valuation of fertilizers.

These prices will be used for the various calculations throughout the present bulletin and as they affect directly the relative returns from the use of the different phosphates, it is important that they receive thorough consideration. Many of the phosphates are not now actively sold in the market and therefore have no definite commercial value at the present time. These have been valued almost entirely on the basis of composition, and present cost of phosphoric acid in similar forms.

The nitrogen-containing phosphates, dissolved bone and fine ground bone, are valued only on the basis of their content of phosphoric acid, which accounts for the low prices given to them. The cost of the nitrogen in them was not included in the prices for the reason that such amounts of nitrogen were supplied in the general manures that no increase in crop was expected to result from that in the bones.

No similar deduction was made from the price of the Thomas slag phosphate on account of the lime in it, because even in the limed plats the acidity was never fully neutralized; and since there was a probability that the lime was frequently beneficial it seemed best to allow the price to be influenced by the lime content as is the case commercially.

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*Bull. 114 (1906) and 118 (1907).

Since the principal sources of phosphoric acid at the present time are the dissolved phosphate rock, fine ground bone, Thomas slag phosphate and raw phosphate rock or floats, it is expected that the attention of the reader will be given principally to the effect of these. In Table IV it may be seen that about twice as much phosphoric acid was applied in the raw phosphate rock as in the other three averaged. These amounts and the cost of the same should not be overlooked when observing the crop yields given in Tables V and VI, and the crop values given in Table VII, resulting from a unit of phosphoric acid applied.

TABLE IV.—*Sources and amounts of phosphoric acid applied per one-tenth of an acre in case of the different plats,** 1894–1898.

SOURCE OF PHOSPHORUS.	Cost per ton as source of phosphorus.	Application of the phosphate per one-tenth acre. Lbs.			Phos. acid applied in the 5 yrs. $\frac{1}{10}$ acre. Lbs.	Cost of the phos. acid at present prices.
		1894.	1895.	Total for 1896–7–8.		
Dissolved boneblack	$15.00	60.0	60.0	60.0	31.8	$1.35
Dissolved bone	14.00	50.4	55.0	45.0	25.0	1.05
Dissolved phosphate rock	13.00	92.7	120.0	73.1	44.5	1.86
Fine ground bone	19.00	42.3	43.9	43.9	35.0	1.24
Thomas slag phosphate	14.00	76.6	66.0	66.0	38.4	1.46
Raw phosphate rock	11.00	92.7	94.1	94.1	73.9	1.54
Raw Redonda phosphate	15.00	52.8	52.9	52.9	56.0	1.19
Roasted Redonda phosphate	33.00	33.0	33.0	33.0	45.3	1.63
No phosphate	0	0.0	0.0	0.0	0.0	0.00
Double superphosphate	37.00	0.0	31.1	25.7	†26.5	†1.05

*The dimensions of each plat are 30 x 193.6 feet, and comprise two-fifteenths of an acre; but, in harvesting, the crop on the edges and ends of the plat is usually eliminated and the product from only one-tenth of an acre is weighed, as recorded in the following tables.

†During four years instead of five, since double superphosphophate was not included in the experiment until 1895.

TABLE V.—*Pounds of corn grown in* 1894 *per one-tenth acre.*

SOURCE OF PHOSPHORUS.	On limed plat.			On unlimed plat.		
	Hard ear-corn.	Soft ear-corn.	Stover.	Hard ear-corn.	Soft ear-corn.	Stover.
Dissolved boneblack	304	35	278	234	44	104
Dissolved bone	227	43	204	165	37	137
Dissolved phosphate rock	263	34	236	216	29	191
Fine ground bone	160	40	145	132	38	140
Thomas slag phosphate	204	38	182	150	28	148
Raw phosphate rock	64	56	166	83	63	108
Raw Redonda phosphate	84	24	151	75	35	116
Roasted Redonda phosphate	140	38	145	61	38	76
No phosphate	144	52	149	126	17	113

TABLE VI.—*Pounds of crops grown from* 1895–1898 *per one-tenth acre.*

SOURCE OF PHOSPHORUS.	Oats, 1895.				Hay, 1896-7-8.	
	On limed plat.		On unlimed plat.		On limed plat.	On unlimed plat.
	Grain.	Straw.	Grain.	Straw.		
Dissolved boneblack	118	566	96	384	1,649	712
Dissolved bone	96	920	101	480	1,463	601
Dissolved phosphate rock	103	619	113	797	1,621	680
Fine ground bone	87	584	84	646	1,771	948
Thomas slag phosphate	94	646	91	529	1,685	1,096
Raw phosphate rock	70	480	76	444	1,699	832
Raw Redonda phosphate	61	409	50	370	1,129	385
Roasted Redonda phosphate	41	280	53	358	1,568	392
No phosphate	47	437	35	286	1,264	203
Double superphosphate	82	498	80	331	1,464	371

TABLE VII.—*Relative crop values in dollars for an equal cost and amount of phosphoric acid applied*, 1894–8.

SOURCE OF PHOSPHORUS.	VALUE OF CROPS OF 5 YEARS, 1/10 ACRE.		INCREASE IN CROP VALUES DUE TO THE PHOSPHATES, 1/10 ACRE.		INCREASE PER $1 PAID FOR PHOSPHORIC ACID.		INCREASE PER 100 LBS. PHOSPHORIC ACID.	
	Limed.	Unlimed.	Limed.	Unlimed.	Limed.	Unlimed.	Limed.	Unlimed.
Dissolved boneblack	$22.04	$12.08	$6.99	$6.78	$5.18(1)	$5.02(4)	$21.99(1)	$21.33(4)
Dissolved bone	20.47	10.93	5.42	5.63	5.16(2)	5.36(3)	21.70(2)	22.54(3)
Dissolved phosphate rock	21.19	13.68	6.14	8.38	3.30(5)	4.50(5)	13.81(5)	18.86(5)
Fine ground bone	20.45	13.70	5.40	8.40	4.35(3)	6.77(1)	15.43(3)	24.00(2)
Thomas slag phosphate	20.77	14.73	5.75	9.43	3.92(4)	6.46(2)	14.90(4)	24.56(1)
Raw phosphate rock	18.17	11.25	3.12	5.95	2.03(7)	3.86(6)	4.22(7)	8.06(7)
Raw Redonda phosphate	13.26	6.80	(—) 1.79	1.50	(—) 1.50(9)	1.26(8)	(—) 3.19(9)	2.68(9)
Roasted Redonda phosphate	16.62	6.56	1.57	1.26	.96(8)	.77(9)	3.46(8)	2.78(8)
No phosphate	15.05	5.30	....	....	....	....	....	....
Double superphosphate	*14.98	*5.54	2.39	2.22	2.27(6)	2.11(7)	9.03(6)	8.39(6)

*Does not include a corn crop for 1894, as these plats had not then been introduced.

The prices assigned to the crops are as follows: Corn, hard ears, 85 cents a bu.; soft ears, 28 cents a bu.; stover, $7.00 a ton; oats, grain, 50 cents a bu.; straw, $8.00 a ton; hay, $16.00 a ton.

Within the five-year period now being considered, the limed plats received at the time they were entered in the experiment slaked lime at the rate of one ton to the acre. The increased value in crops due to the lime, during this period, is shown in Table VII. It may be seen that this amounted to about $100 an acre ($9.75 per 1/10 acre) where no phosphate was applied, and the same where certain of the phosphates were added. However, especially with the sources of insoluble phosphoric acid, fine ground bone, Thomas slag phosphate, raw phosphate rock and raw Redonda phosphate, the increase in crop values due to the application of lime was considerably less; which means that these sources caused a greater increase in crop values over those of the no-phosphate plat in case of the unlimed soil than in case of the limed soil. This may be attributable to a greater availability of the sources of insoluble phosphoric acid in the acid unlimed soil than in the less acid limed soil, and to basic residues, which would be expected to exert their greatest effect on the unlimed soil. In the case of the Thomas slag phosphate, the latter reason would be of especial importance; in fact there was the least difference between the limed and the unlimed plats in the case of this phosphate.

It may be seen that with few exceptions the relative increase in the value of the crops from the different phosphate plats, as compared with the value from the no-phosphate plats was in the same order whether calculated on the basis of a 100 pounds of phosphoric acid applied or on one dollar's worth of phosphate, so that discussion of the results may be confined to the latter comparison.

The five phosphates which gave the largest increase in value of the crops from a dollar's worth of phosphate are those mentioned first in the table: of these the fine ground bone and Thomas slag phosphate ranked first on the unlimed plats and the dissolved boneblack and dissolved bone on the limed plats. On the unlimed plats the first two mentioned were doubtless superior because they are unacidulated. The dissolved phosphate rock ranked fifth on both the limed and unlimed plats and was markedly superior to the raw or unacidulated phosphate rock. The Redonda, or aluminum and iron phosphates were the poorest sources.

In comparing the relative increase in crop value due to the phosphatic applications to the limed and unlimed plats, it should be realized that even where no phosphate was applied, the lime itself naturally increased the crops, so that an equal increase due to a phosphate used both with and without lime must result in a crop on the limed plat which more nearly approached the maximum than on the unlimed plat, and that the nearer the approach to a maximum crop, the less increase would be expected from a given amount of any nutrient.

THE PERIOD FROM 1894 TO 1904, THE COMBINED PHOSPHATIC APPLICATIONS HAVING BEEN ADJUSTED TO AN EQUAL PHOSPHORUS BASIS.

The details of the experiment between the years 1899 and 1904, inclusive, were published in Bulletins 114 and 118, a few of which are still available, so that only a summary is necessary for that period.

The plats remained seeded down in 1899, but were planted to corn in 1900, miscellaneous crops in 1901, soy beans in 1902, miscellaneous crops in 1903, and oats in 1904. In 1903, a second ton of slaked lime per acre was added only to those plats which had been limed at the beginning of the experiment. The total amount of phosphoric acid added to every one of the phosphate plats was equalized by the application of 1902, after which no further applications were made within the period covered by this article; but since some of these were unusually large at that time, it was decided to summarize in Table VIII certain features of the results from the beginning of the experiment to 1904, inclusive, and to consider the results from 1905 to 1913, inclusive, as due strictly to the after-effects of the phosphates.

Soy bean was the only new crop which had occupied the entire field since the period covered by Table VII, and this was valued at $5

TABLE VIII.—*Relative crop values for an equal cost and amount of phosphoric acid applied*, 1894–1904.

SOURCE OF PHOSPHORUS.	Cost of phosphates at present prices, $\frac{1}{10}$ acre.	VALUE OF CROPS OF 11 YEARS, $\frac{1}{10}$ ACRE.		INCREASE PER $1 PAID FOR PHOSPHORIC ACID.		INCREASE IN CROP VALUES DUE TO 73.86 LBS. PHOSPHORIC ACID. $\frac{1}{10}$ ACRE.	
		Limed.	Unlimed.	Limed.	Unlimed.	Limed.	Unlimed.
Dissolved boneblack	$3.18	$59.82	$37.73	$7.21(6)	$6.67(6)	$22.92(5)	$21.21(5)
Dissolved bone	3.21	64.80	43.60	8.69(3)	8.44(4)	27.90(1)	27.08(3)
Dissolved phosphate rock	3.13	61.06	41.25	7.72(4)	7.90(5)	24.16(4)	24.73(4)
Fine ground bone	2.68	64.50	47.00	10.30(1)	11.37(2)	27.60(2)	30.48(2)
Thomas slag phosphate	2.94	63.87	47.70	9.17(2)	10.61(3)	26.97(3)	31.18(1)
Raw phosphate rock	1.55	48.08	35.36	7.21(5)	12.15(1)	11.18(7)	18.84(6)
Raw Redonda phosphate	1.53	36.22	24.44	(—) .44(9)	5.18(7)	(—) .68(9)	7.92(8)
Roasted Redonda phosphate	2.58	47.92	23.36	4.27(8)	2.65(8)	11.02(8)	6.84(9)
No phosphate	....	36.90	16.52	....	....	....	....
Double superphosphate	3.08	*55.29	*25.07	5.97(7)	2.78(6)	18.39(6)	8.55(7)

*Does not include a corn crop for 1894, as these plats had not been then introduced.

a ton, green. During the two years devoted to miscellaneous crops only a small area was occupied by each crop, and the prices of these will be given on page 546 in connection with the prices of other crops yet to be considered.

Although the second ton of lime to the acre was added only one year previous to the last crop included in Table VIII it is of interest to consider briefly again the effect of lime on the value of the crops; this time during the eleven years now under discussion. Where no phosphate was applied the crop values were increased about $200 an acre by the occasional addition of lime with the nitrate of soda and potash salts. A departure from this difference in the case of any one of the various phosphates is attributable to some specific difference between the effect of the particular phosphate in the limed and unlimed soil. Although this matter will be considered more fully in subsequent pages when the results of the last nine years have been considered, a few suggestions now will add interest to the table.

Only from the standpoint of reducing the natural acidity of the soil, those phosphates leaving alkaline or basic residues would have more opportunity to increase the crops on the unlimed than on the limed soil, thereby lessening the difference from where no phosphate was used. It may be observed again that this difference was less in case of those phosphates which had undergone no special treatment to increase their content of available phosphoric acid, namely: bone, slag phosphate, raw phosphate rock and raw Redonda phosphate.

Considered on the other hand only as sources of available phosphorus, any phosphate which proved to be more available in the unlimed than in the limed soil would cause a greater relative increase in such soil, and the benefit from liming would thereby be lessened. The same would be true to a less extent, even of any phosphate equally available in the limed and unlimed soil, for the reason that the growth in general in the limed soil approached more nearly to the maximum, consequently there was less opportunity there for a given amount of available phosphorus to increase the growth.

The greater increase caused by the ignited Redonda phosphate in the limed than in the unlimed soil is doubtless due to the increased availability of its phosphorus under those conditions. On the other hand, in case of raw phosphate rock and bone, a portion at least of the greater increase in the unlimed soil is probably attributable to the greater solvent effect of such soil on these sources of tricalcium phosphate.

Without further discussion until later of the probable reasons for the results, it may be pointed out that the best returns from a dollar expended for phosphoric acid was when it was purchased in raw phosphate rock, ground bone and Thomas slag phosphate applied to the unlimed soil; when applied to the limed soil, however, the returns from the raw phosphate rock were less than from ground bone, Thomas slag phosphate, dissolved bone and dissolved phosphate rock.

Although many of the phosphates caused a greater increase over the no-phosphate plats, in the unlimed than in the limed soil, it should be observed that the value of the total crops was not larger, because where only nitrogen and potassium were added, the crops as a whole were much smaller without the lime.*

THE PERIOD FROM 1905 TO 1913, WHEN THE AFTER-EFFECTS WERE STUDIED.

Because the results subsequent to 1904 have not been published heretofore, tables containing the individual crop yields from 1905 to 1913, inclusive, will be given in subsequent pages.

It will be recalled that no further application of the phosphates was made during this period and that the results represent the after-effects of the different phosphates, all of which had supplied previously the same amount of phosphorus.

Nitrate of soda and potash salts were applied annually as heretofore to all plats alike. The applications were equal to the following in pounds per acre, during the different years:

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*The average annual application of nitrogen, and potassium oxid, to these plats was 44 and 115 pounds to the acre, respectively, from 1894 to 1904, inclusive.

	1905.	1906.	1907.	1908.	1909.	1910.	1911.	1912.	1913.
Nitrogen.........	50	50	54	40	60	60	40	40	104
Potassium oxid...	200	150	150	75	150	150	60	150	175

The third application of lime was made in 1911 to the plats previously limed; it consisted of slaked lime containing 49.93 per cent. of calcium oxid and 6.14 per cent. of magnesium oxid, and was equivalent to 1,500 pounds of calcium oxid per acre.

Redtop had been sown with oats in 1904 and allowed to grow on the plats in 1905 and 1906. In July, 1906, Hungarian millet was sown, but the crop was not harvested. The hay yields are in Table IX.

With the redtop in 1905 there was considerable yarrow, *achillea millefolium*, which was pulled and weighed green. The growth of this weed was shown to be retarded by acid soil, for there was more than ten times as much weight from the limed as from the unlimed plats, whereas the redtop was only about one-fifth heavier on the limed than on the unlimed plats in 1905 and no heavier in 1906. Double superphosphate was the only phosphate which showed much after-effect in 1906, although in 1905 the phosphate plats produced considerably more, with one exception, than the no-phosphate plats.

TABLE IX.—*Pounds of redtop hay per one-tenth acre.*

	HAY, 1905.		HAY, 1906.		TOTAL, 1905 AND 1906.	
	Limed.	Unlimed.	Limed.	Unlimed.	Limed.	Unlimed.
Dissolved boneblack.......	634	461	367	303	1,001	764
Dissolved bone............	570	460	320	338	890	798
Dissolved phosphate rock...	555	513	350	343	905	856
Fine ground bone..........	538	468	368	383	906	851
Thomas slag phosphate.....	593	473	353	367	945	840
Raw phosphate rock........	540	465	350	390	890	855
Raw Redonda phosphate...	460	458	298	327	758	785
Roasted Redonda phosphate.	540	458	298	327	758	785
No phosphate.............	491	354	330	360	821	714
Double superphosphate.....	570	480	405	420	975	900

In 1907 a large number of miscellaneous crops were planted crosswise the plats. Only in case of the millets, oats and clover were there more than six rows each; therefore, the actual weights, which may be found in Tables X to XVI, should be considered as furnishing no more than an *indication* of the comparative after-effects of the phosphates on different kinds of crops; consequently but few special comments will be made.

In Table X it is shown that the lime benefitted percentagely, the alfalfa and crimson clover more than the oats and cowpeas. Only with the oats was there any appreciable after-effect of the raw Redonda phosphate, but since this phosphate is practically useless under most circumstances it will usually be omitted from further discussion: on oats there was an after-effect of all the phosphates on the limed plats.

Millet and corn, the results with which are recorded in Table XI, are crops which are quite tolerant of acid soil and although the growth of golden millet was usually better on the limed plats, the Japanese millet (*panicum crus-galli*) and corn frequently produced as much on the unlimed as on the limed plats; this was true of the ear corn, however, rather than of the stover. On the no-phosphate plats the lime about doubled the yields of all the crops, perhaps mainly in case of these crops by increasing the availability of the soil phosphorus.

The weights of tomatoes and potatoes given in Table XII show that only in case of potatoes with Thomas slag phosphate, was a greater crop secured from the unlimed than from the limed plat, and even then there was not a greater weight of *large* potatoes.

It is shown in Table XIII that only in case of Thomas slag phosphate and raw phosphate rock was a greater weight of cucumbers obtained from the unlimed than from the limed plats, although with the summer squash the crop was practically as good or better on the unlimed plats in half the cases. The after-effect of the phosphates was generally considerable.

The three kinds of beets included in Table XIV were a failure on the unlimed plats because of the intolerance of beets to acid soil: this is in

TABLE X.—*Pounds of green cowpea, alfalfa, clover and oats, from a few rows crosswise the plats in* 1907.

	WHIPPOORWILL COWPEAS.		ALFALFA.		CRIMSON CLOVER.		CLYDESDALE. OATS.	
	Limed.	Unlimed.	Limed.	Unlimed.	Limed.	Unlimed.	Limed.	Unlimed.
Dissolved boneblack	191	128	19.1	19.	83	29	100	67
Dissolved bone	173	118	20.3	17.8	80	60	106	81
Dissolved phosphate rock	139	120	19.5	15.5	69	43	107	79
Fine ground bone	143	129	18.6	16.8	78	53	116	93
Thomas slag phosphate	139	105	17.7	17.6	87	67	101	69
Raw phosphate rock	125	102	22.2	13.3	72	62	124	78
Raw Redonda phosphate	116	85	18.7	5.3	43	16	84	52
Roasted Redonda phosphate	179	111	23.4	6.5	78	20	110	32
No phosphate	121	83	19.0	4.7	60	15	63	34
Double superphosphate	150	126	20.0	2.3	77	19	89	36

TABLE XI.—*Pounds of green millet and field-cured corn from eight and four rows, respectively, crosswise the plats in* 1907.

	MILLET.				POTTER'S EXCELSIOR SWEET CORN.			
	Japanese.		Golden.		Limed.		Unlimed.	
	Limed.	Unlimed.	Limed.	Unlimed.	Ear Corn.	Stover.	Ear Corn.	Stover.
Dissolved boneblack	109	81	51	68	24	49	41	55
Dissolved bone	98	98	86	69	33	67	34	43
Dissolved phosphate rock	91	84	85	63	31	61	34	44
Fine ground bone	102	132	93	86	34	65	44	59
Thomas slag phosphate	98	100	91	72	36	78	33	42
Raw phosphate rock	111	82	93	59	39	48	33	39
Raw Redonda phosphate	109	55	82	39	32	47	25	28
Roasted Redonda phosphate	115	73	107	58	47	60	31	31
No phosphate	70	40	78	39	33	46	19	20
Double superphosphate	91	42	87	57	36	50	24	25

TABLE XII.—*Pounds of tomatoes and potatoes from two and five rows, respectively, crosswise the plats in* 1907.

	TRUCKER'S FAVORITE TOMATO.				GREEN MOUNTAIN POTATOES.			
	Limed.		Unlimed.		Limed.		Unlimed.	
	Ripe.	Green.	Ripe.	Green.	Large.	Small.	Large.	Small.
Dissolved boneblack	125	107	43	112	124	36	9	63
Dissolved bone	107	132	41	122	110	41	10	78
Dissolved phosphate rock	72	142	67	141	107	37	14	68
Fine ground bone	83	154	67	141	107	37	22	88
Thomas slag phosphate	77	146	41	119	69	40	55	78
Raw phosphate rock	58	147	16	74	45	30	0	76
Raw Redonda phosphate	58	80	5	39	37	24	0	20
Roasted Redonda phosphate	121	138	20	73	78	43	0	20
No phosphate	51	70	14	43	81	35	0	22
Double superphosphate	49	114	5	15	40	22	0	33

TABLE XIII.—*Number and pounds of cucumbers and summer squashes from three rows each, crosswise the plats in* 1907.

	WHITE SPINE CUCUMBERS.				SUMMER CROOKNECK SQUASHES.			
	Limed.		Unlimed.		Limed.		Unlimed.	
	Number.	Wt.	Number.	Wt.	Number.	Wt.	Number.	Wt.
Dissolved boneblack	664	59	326	33	187	176	115	92
Dissolved bone	670	61	388	36	164	156	201	183
Dissolved phosphate rock	474	39	356	32	180	176	208	177
Fine ground bone	605	53	483	42	172	163	173	162
Thomas slag phosphate	510	52	615	60	179	157	187	158
Raw phosphate rock	394	35	580	51	168	169	175	158
Raw Redonda phosphate	236	21	239	20	99	60	117	69
Roasted Redonda phosphate	592	54	222	19	181	169	97	76
No phosphate	360	30	120	12	151	119	64	41
Double superphosphate	879	86	423	39	179	173	112	98

TABLE XIV.—*Pounds of beets and dry shelled beans from three or four rows crosswise the plats in* 1907.

	RED GLOBE MANGEL WURZELS.		DANISH IMPROVED SUGAR BEETS.		EARLY TABLE BEETS.		RED VALENTINE BEANS.	
	Limed.	Unlimed.	Limed.	Unlimed.	Limed.	Unlimed.	Limed.	Unlimed.
Dissolved boneblack	110	0	78	0	12.5	0	4.4	3.2
Dissolved bone	79	0	62	0	15.	0	5.4	3.3
Dissolved phosphate rock	93	0	50	0	6.5	0	5.0	3.5
Fine ground bone	141	0	64	0	9.	.3	5.8	5.8
Thomas slag phosphate	183	9	77	0	30.	.5	5.1	3.9
Raw phosphate rock	80	0	28	0	3.	0	5.0	3.7
Raw Redonda phosphate	1	0	2	0	0.	0	3.2	2.4
Roasted Redonda phosphate	39	0	26	0	4.	0	5.8	3.8
No phosphate	4	0	5	0	1.5	0	3.3	1.6
Double superphosphate	100	0	65	0	1.6	0	4.4	3.3

marked contrast to the results with beans considered in the same table. The weights of the beets illustrate the sensitiveness of this kind of a crop to differences in the amount of available phosphorus, as well as to differences in the acidity of the soil; they bring out marked differences in the after-effect of the different phosphates. Even on the limed plat, which was nevertheless somewhat acid, the alkalinity of the Thomas slag phosphate has resulted in the largest yield of beets. There is a marked inferiority in the after-effect of the raw phosphate rock and the Redonda phosphates. The beans do not exhibit any such marked contrasts.

It may be seen in Table XV that the cabbage was very sensitive to the acidity on the unlimed plats, where the Thomas slag phosphate was again pre-eminent, and that differences in the after-effect of the phosphates in general are quite marked, as is also the case with the two varieties of turnips recorded in the same table.

Table XVI furnishes additional examples of the extreme sensitiveness of certain market-garden crops to the conditions which existed in the plats in 1907, five years after the application of any phosphate and four years after liming.

TABLE XV.—*Pounds of turnips and cabbage from seven and four rows, respectively, crosswise the plats in* 1907.

	Strap-Leaf Flat Turnips.		Budlong Turnips.		Surehead Cabbage.			
					Limed.		Unlimed.	
	Limed.	Unlimed.	Limed.	Unlimed.	Heads.	Trimmings.	Heads.	Trimmings.
Dissolved boneblack.........	97	31	118	77	90	106	31	31
Dissolved bone.............	106	46	121	18	82	100	45	28
Dissolved phosphate rock.....	122	10	69	3	113	108	0	24
Fine ground bone...........	155	76	175	16	170	129	27	67
Thomas slag phosphate......	121	43	86	144	171	125	67	87
Raw phosphate rock.........	101	75	70	12	117	137	28	43
Raw Redonda phosphate.....	15	0	3	0	7	36	0	7
Roasted Redonda phosphate..	42	6	47	0	39	77	0	6
No phosphate..............	10	20	5	0	5	22	0	4
Double superphosphate......	109	84	100	19	72	74	0	22

TABLE XVI.—*Pounds of fresh celery, lettuce, spinach and peas from a few rows crosswise the plats in* 1907.

	Celery.		Thorburn's Glasshouse Lettuce.		New Zealand Spinach.		Nott's Excelsior Peas.	
	Limed.	Unlimed.	Limed.	Unlimed.	Limed.	Unlimed.	Limed.	Unlimed.
Dissolved boneblack.........	8.0	.7	14.0	.2	187	78	28.7	9.0
Dissolved bone.............	5.0	7.3	26.8	.2	247	26	29.8	8.1
Dissolved phosphate rock.....	8.5	.6	11.3	.1	156	28	27.4	12.2
Fine ground bone...........	8.8	1.0	15.3	.8	208	133	26.2	15.6
Thomas slag phosphate......	8.3	1.8	24.3	2.9	207	109	24.3	17.9
Raw phosphate rock.........	7.3	1.9	12.0	0	182	17	17.6	14.6
Raw Redonda phosphate.....	3.0	.5	5.1	0	46	1	15.1	4.8
Roasted Redonda phosphate..	4.5	.5	26.5	0	193	2	20.5	5.6
No phosphate..............	4.8	.6	8.0	0	81	1	16.4	3.4
Double superphosphate......	4.0	.6	17.3	0	200	2	28.3	5.2

In 1908 nearly the entire area was planted to corn. Therefore the weights, which may be found in Table XVII, warrant more comment than those of any single crop of the preceding year, because of the small area which was then used for each of the miscellaneous crops. There is practically no difference in the yield of ear corn from the limed and unlimed plats. Except for the lower yields from the plats which received no phosphate and raw Redonda phosphate the differences in yields from the various plats are probably mostly within the limit of experimental error. A few turnips which were grown at the ends of the plats however, showed decided contrasts, as was expected of this crop, and the results have been placed in the same table with those of the corn so that the comparison may be readily made.

TABLE XVII.—*Pounds of R. I. White Cap corn per one-tenth acre, and of a small area of Strap-leaf Flat turnips at the ends of the plats*, 1908.

	R. I. WHITE CAP CORN.				STRAP-LEAF FLAT TURNIPS.	
	Limed.		Unlimed.			
	Ear Corn.	Stover.	Ear Corn.	Stover.	Limed.	Unlimed.
Dissolved boneblack	445	395	423	310	146	15
Dissolved bone	465	380	438	330	88	20
Dissolved phosphate rock	416	299	436	300	34	28
Fine ground bone	426	310	475	355	116	56
Thomas slag phosphate	422	270	485	360	142	108
Raw phosphate rock	408	310	448	325	147	12
Raw Redonda phosphate	243	160	290	200	10	0
Roasted Redonda phosphate	486	380	325	220	20	0
No phosphate	301	265	244	140	5	0
Double superphosphate	458	430	396	250	80	0

In 1909 the entire area was planted to potatoes, after which winter rye was sown. This was cut in June of the following year, when in bloom. The weights of these two crops may be found in Table XVIII.

The only instance in which the yield of large or merchantable potatoes from an unlimed plat nearly equalled that from a limed plat was in case of the plats which had received Thomas slag phosphate, although the combined yield of large and small potatoes was about the same from the limed and unlimed plats of both the dissolved and the fine ground bone and the raw phosphate rock. The large potatoes equalled about nine-tenths of the total yield from the entire limed area, and only about one-half the total yield from the unlimed area.

TABLE XVIII.—*Pounds per one-tenth acre of potatoes grown in* 1909 *and of green rye harvested in* 1910.

	POTATOES.				**RYE.**	
	Limed.		**Unlimed.**			
	Large.	**Small.**	**Large.**	**Small.**	**Limed.**	**Unlimed.**
Dissolved boneblack.......	1,210	149	482	421	1,020	660
Dissolved bone............	1,169	124	658	492	890	395
Dissolved phosphate rock...	1,089	91	649	354	740	340
Fine ground bone..........	999	83	805	298	820	460
Thomas slag phosphate.....	980	192	939	223	910	500
Raw phosphate rock.......	896	91	558	366	600	230
Raw Redonda phosphate....	596	87	76	362	145	50
Roasted Redonda phosphate.	1,086	113	59	364	800	330
No phosphate.............	659	70	65	291	230	180
Double superphosphate.....	1,053	92	227	409	610	470

Although the after-effect of the roasted Redonda phosphate was about equal to that of many of the better phosphates on the limed area, it was of no importance on the unlimed soil.

Norcross and Green Mountain potatoes each occupied half of the number of lengthwise rows of each plat. On the limed plats where conditions were more favorable for growth, there was a small difference in favor of the Norcross variety, but not sufficient to have any positive significance.

The rye grew much better on the limed than on the unlimed plats in spite of the fact that this crop is quite tolerant of soil acidity. This may be taken as an indication that there was a larger supply of available nutrients in the limed soil. Although probably the growth was controlled principally by the amount of available phosphorus, it is probable that the 25 pounds of nitrogen per acre which was supplied in nitrate of soda as a top dressing (along with 150 pounds of potash) was not sufficient for the rye, so that the well-known influence of lime in increasing the available supply of this nutrient would have an opportunity to exert itself.

It should be recognized also that the after-effect of lime during the years when no phosphates were applied may be attributable to liberation of phosphorus quite as much as to improvement in the soil reaction, and that with crops such as rye, which are quite independent of this reaction, a difference in the availability of the phosphorus would be expected to be the main factor influencing growth. (See figure 1).

After the rye was removed in June of 1910, Hungarian millet was sown, using for the only fertilizer 35 pounds per acre of nitrogen in nitrate of soda. In the following spring, lime was applied as stated elsewhere, to those plats which had been previously limed, nitrogen and potassium added as usual, and the plats seeded down with oats (See figure 2), timothy, redtop, medium red clover and alsike clover. The yields of the millet, oats and rowen are given in Table XIX. The poorest yelds of millet were as usual from the plats which had received no phosphate and raw Redonda phosphate, followed by those from the plats to which raw phosphate rock and roasted Redonda phosphate had been added.

Almost without exception the oat straw was heavier where the fresh application of lime was made, but the yield of grain was generally less there. When the oats were quite young, they presented an abnormal appearance, the cause of which was not ascertained. This was particularly noticeable on some of the limed plats and is mentioned in this connection as a probable explanation of the decreased yields of grain on most of the limed plats. It may be seen that the rowen which was cut subsequently to the oats was markedly benefitted by the liming.

TABLE XIX.—*Pounds per one-tenth acre of Hungarian hay grown after rye in* 1910, *and of oats and the following rowen grown in* 1911.

	HUNGARIAN.		OATS.				ROWEN.	
			Limed.		Unlimed.			
	Limed.	Unlimed.	Grain.	Straw.	Grain.	Straw.	Limed.	Unlimed.
Dissolved boneblack	535	450	75	130	97	108	165	50
Dissolved bone	545	480	68	162	108	132	173	35
Dissolved phosphate rock	560	480	72	158	107	108	158	24
Fine ground bone	550	470	46	114	113	112	180	28
Thomas slag phosphate	530	460	48	127	117	133	195	40
Raw phosphate rock	490	400	85	165	101	109	180	28
Raw Redonda phosphate	340	220	75	125	85	90	128	66
Roasted Redonda phosphate	510	400	80	150	100	115	188	41
No phosphate	390	260	84	131	42	43	143	73
Double superphosphate	580	460	98	177	67	88	180	57

In Table XX may be found the weights of the hay harvested in 1912 and 1913, and also those of some turnips which were planted in drills on July 17 after the removal of the hay crop of 1913. French turnips and strap-leaf flat turnips were planted in alternate, lengthwise rows, and received 50 pounds of nitrogen and 75 pounds of potash per acre in nitrate of soda and muriate of potash.

The growth of the turnips was very much retarded by dry weather, but it served to show in a decided way the after-effects of the different phosphates even though none of them had been added since 1902, eleven years before. The raw Redonda phosphate is the only one which failed to produce more crop than that from the plat to which no phosphate had been applied within the history of the experiment, and which received only nitrate of soda and potash, aside from the lime. It seems quite remarkable that soil manured in such a way, without any phosphorus added for at least twenty years, should produce 2.65 tons of field-cured hay as was the case in 1913 on the limed plat; the turnips, however, were practically unable to grow under such circumstances.

Illustrations Showing the After-Effects on the Limed Plats of the Same Amount of Phosphorus Applied Prior to 1903 in the Different Sources Mentioned Below.

Fig. 1—Rye, 1910.

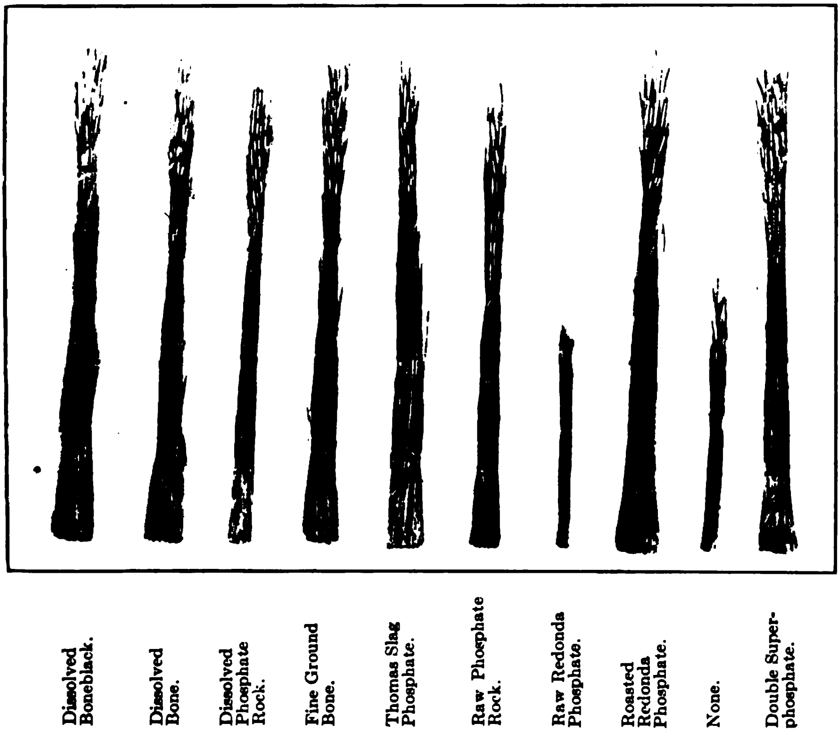

Fig. 2—Oats, 1911.

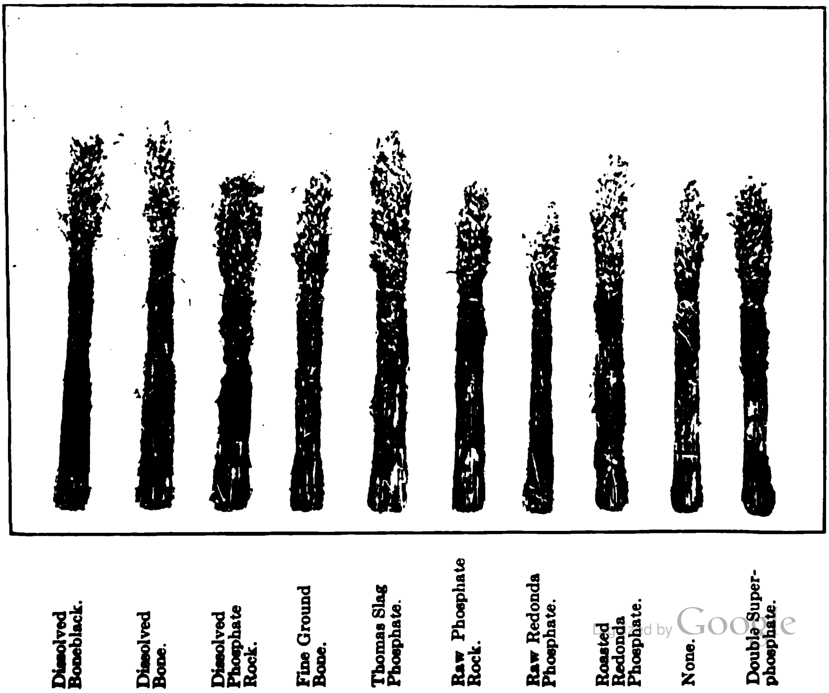

ILLUSTRATION SHOWING THE AFTER-EFFECTS OF THE SAME AMOUNT OF PHOSPHORUS APPLIED PRIOR TO 1903 IN THE DIFFERENT SOURCES MENTIONED BELOW; ALSO THE EFFECT OF LIME IN RETAINING TIMOTHY IN THE HAY; ALL FROM THE SAME SEED MIXTURE.

Fig. 3—Hay, 1913.

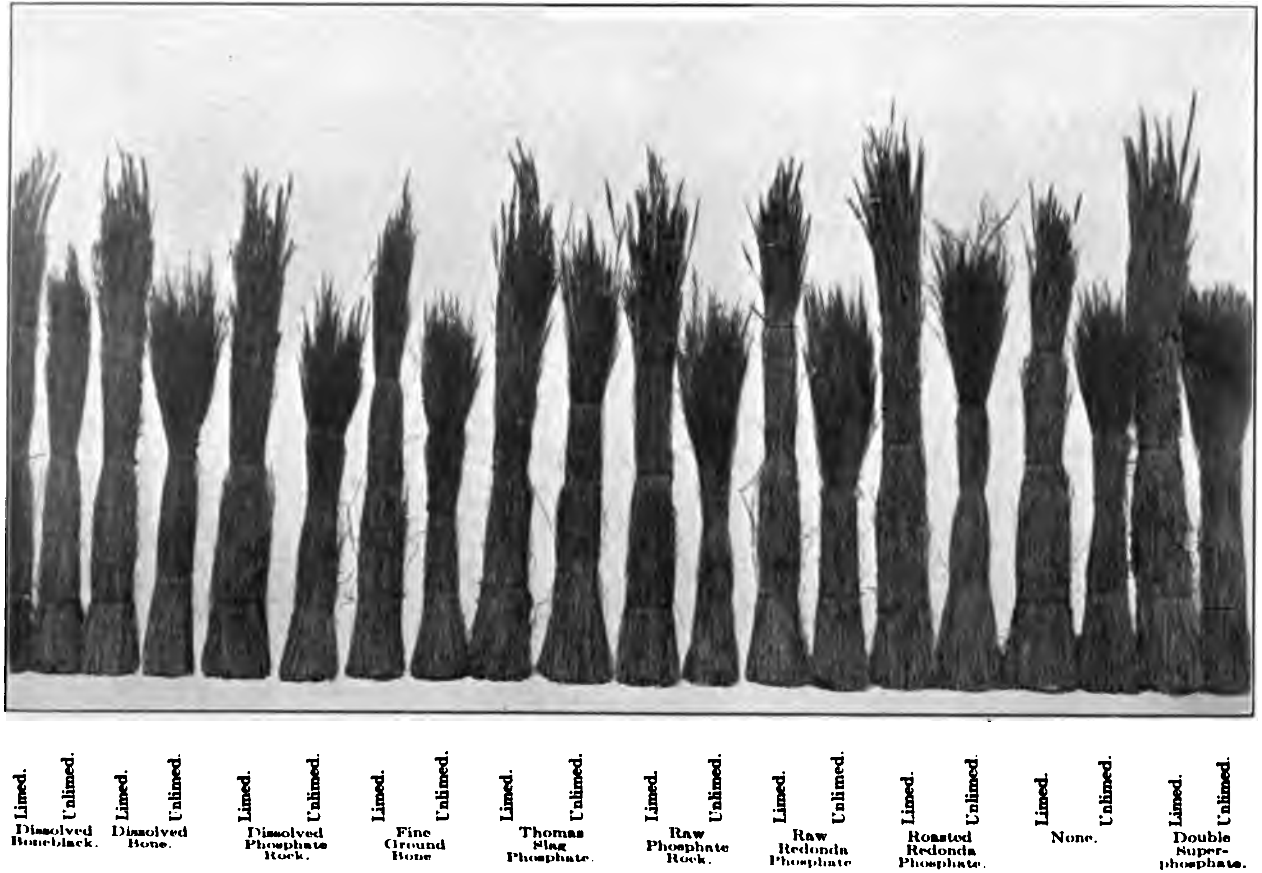

TABLE XX.—*Pounds per one-tenth acre of mixed hay grown in* 1912, *and of hay (See figure 3) and turnips grown in* 1913.

	HAY, 1912.		HAY, 1913.		TURNIPS, 1913.			
					Flat.		French.	
	Limed.	Un-limed.	Limed.	Un-limed.	Limed.	Un-limed.	Limed.	Un-limed.
Dissolved boneblack	580	290	640	440	720	304	204	58
Dissolved bone	550	230	580	290	334	100	116	24
Dissolved phosphate rock	535	270	570	330	228	124	42	26
Fine ground bone	545	320	570	350	400	152	144	28
Thomas slag phosphate	590	370	580	390	320	242	130	64
Raw phosphate rock	510	280	560	360	406	136	128	22
Raw Redonda phosphate	400	220	540	360	92	16	20	6
Roasted Redonda phosphate	580	340	660	320	316	52	100	10
No phosphate	400	240	530	360	162	28	38	6
Double superphosphate	620	400	770	430	224	128	60	30

DISCUSSION OF THE FIELD RESULTS OF THE EXPERIMENT AS A WHOLE.

The relative crop values per unit of phosphoric acid applied were given in Table VII for the first five years of the experiment when the phosphorus was applied on the basis of equal cost, and again in Table VIII for the first eleven years, during the latter part of which time the phosphatic applications had been such that finally an equal amount instead of an equal cost of phosphoric acid had been applied.

The subsequent nine years have been devoted especially to showing the decided after-effects of the phosphates. Inasmuch as in 1914 phosphoric applications were begun again, it appears best to bring together in Table XXI the combined data for the preceding twenty years, concerning the relative crop values per unit of phosphoric acid applied.

The following prices were adopted in valuing the crops:

Alfalfa, green, t	$8.00	Hay, t	$16.00
hay, t	16.00	Hungarian, t	12.00
Barley, green, t	5.00	Lettuce, cwt	2.00
Beans, adzuki, t	5.00	Mangel wurzels, t	5.00
soy, t	5.00	Millet, green, t	4.00
valentine, bu	2.00	hay, t	12.00
Beets, sugar, t	5.00	Oats, grain, bu	.50
early table, cwt	1.00	straw, t	8.00
Cabbage, cwt	1.00	green, t	5.00
Celery, lb	.05	Peas, bu	2.00
Clover, green, t	4.00	Potatoes, large, bu	.75
Corn, sweet, ears, cwt	1.00	small, bu	.25
stover, green, t	4.00	Rowen, hay, t	12.00
" dry, t	7.00	Spinach, cwt	2.00
hard, bu	.85	Squash, cwt	1.00
soft, bu	.28	Tomatoes, ripe, bu	.75
Cowpea, green, t	4.00	green, bu	.50
Cucumbers, bu	1.00	Turnips, Budlong, bu	.50
		flat, bu	.25

The raw Redonda phosphate was so unavailable under the conditions of the field experiment, where the soil of even the limed plat was somewhat acid, that it was thought desirable to ascertain whether perchance the material would prove of any value in a neutralized soil containing an excess of calcium carbonate. Accordingly F. R. Pember conducted in the greenhouse in 1915 a pot experiment for which soil from the unlimed raw Redonda phosphate plat of the field experiment had been taken before plowing in 1914. Generous amounts of nitrogen and potassium were added to all pots, the conditions being such that the growth was controlled by the amount of available phosphorus.

Oat plants were grown in both unlimed and limed soil with raw Redonda phosphate, as well as with dissolved phosphate rock as sources of phosphorus. The limed soil was first rendered practically neutral with hydrated lime, allowing a number of days' contact with the soil, and then ground limestone at the rate of 2.5 tons per acre was added.

The results were so positive after the first few weeks that the experiment was discontinued before the plants had time to make their full growth in order that the general results might be given here.

TABLE XXI.—*Relative crop values for an equal cost and amount of phosphoric acid applied,* 1894–1913.

	AMOUNT OF PHOSPHATES APPLIED, 1/10 ACRE.	COST OF PHOSPHATES AT PRESENT PRICES, 1/10 ACRE.	VALUE OF CROPS, 1/10 ACRE.		INCREASE PER $1 PAID FOR PHOSPHORIC ACID.		INCREASE IN CROP VALUE DUE TO 73.86 LBS. PHOSPHORIC ACID, 1/10 ACRE.	
	Lbs.		Limed.	Unlimed.	Limed.	Unlimed.	Limed.	Unlimed.
Dissolved boneblack	424.3	$3.18	$129.91	$80.48	$16.34(5)	$13.22(6)	$51.95(2)	$42.04(5)
Dissolved bone	458.9	3.21	131.77	85.27	16.76(4)	14.58(4)	53.81(1)	46.83(3)
Dissolved phosphate rock	482.1	3.13	126.65	82.49	15.56(6)	14.07(5)	48.69(5)	44.05(4)
Fine ground bone	282.6	2.68	128.76	95.71	18.96(1)	21.37(2)	50.80(4)	57.27(2)
Thomas slag phosphate	419.9	2.94	128.81	99.70	17.30(3)	20.84(3)	50.85(3)	61.26(1)
Raw phosphate rock	280.9	1.55	104.87	74.32	17.36(2)	23.15(1)	26.91(9)	35.88(6)
Raw Redonda phosphate	204.0	1.53	72.05	46.33	(—) 3.86(9)	5.16(9)	(—) 5.91(9)	7.89(9)
Roasted Redonda phosphate	156.6	2.58	110.80	52.26	12.73(8)	5.36(8)	32.84(7)	13.82(8)
No phosphate	......	....	77.96	38.44	....	....	....	....
Double superphosphate*	166.4	3.08	119.33	60.34	13.43(7)	7.11(7)	41.37(6)	21.90(7)

*This phosphate not having been included until the second year of the experiment is credited here with the average crop of corn produced the first year on the other acidulated phosphate plats.

Even though four times as much phosphorus was added in the raw Redonda phosphate as in the dissolved phosphate rock, it caused no increase in growth either with the acid or with the neutralized soil, showing that this material is valueless as a source of phosphorus for agricultural purposes.

Although the dissolved phosphate rock produced a normal growth, the crop was doing somewhat better in the unlimed than in the neutralized soil, thereby furnishing an indication that the soluble phosphoric acid may have been precipitated, by the excess of limestone, more readily than under the conditions existing in the acid soil, thereby reducing the availability temporarily.

The following statements will assist in the interpretation of Table XXI. The phosphates were applied on an equal phosphorus basis. The cost of the dissolved bone and fine ground bone does not include the cost of the nitrogen in them, since this element was supplied liberally in nitrate of soda. Due to the similarity in the form of the phosphorus, it may be seen that the applications of the acidulated phosphates, dissolved boneblack, dissolved bone, dissolved phosphate rock and double superphosphate, were on practically an equal cost basis also.

Owing to the acid nature of these phosphates, the increase in value of the crops due to their application was less on the unlimed than on the limed plats: the same difference was true of roasted Redonda phosphate, but this was because of its greater availability in the limed soil. The sources of insoluble phosphorus gave a greater increase in crop on the more acid unlimed plats than on those which had been limed: for some reason the raw Redonda phosphate appeared to be actually toxic on the limed plat.

These general observations assist in the consideration of the influence of the lime on the crop values. Where no phosphate was added the application of three tons of slaked lime per acre during the twenty years, costing less than $3 per 1/10 acre, increased the crop values $40 per 1/10 acre, whereas the increase in the presence of raw Redonda phosphate was only $26. In the presence of the water insoluble calcium phosphates the increase from liming was $29 to $33, while in the presence of the acidulated phosphates, it was from $44 to $59. It is obvious that there are two main factors concerning the relative effect of lime in connection with the different phosphates, namely: the physiological acidity or basicity of the phosphate, and its relative degree of availability on the limed and unlimed plats.

The increase in value of the crops due to the different phosphates added on an equal phosphorus basis is obtained by subtracting the value of the crops secured from the no-phosphate plats from the value where any given phosphate was applied, 73.86 pounds of phosphoric acid per one-tenth acre having been added in each phosphate during the experiment. It may be seen that there was a decrease rather than an increase in crop values due to the addition of raw Redonda phosphate to the limed plat and only a slight apparent increase in case of the unlimed plat. This material then seems to be valueless if not actually harmful.

The greatest increase in crop value caused by roasted Redonda phosphate was on the limed soil, where it was superior to the raw phosphate rock under similar conditions; although the reverse was true on the unlimed plats.

Raw phosphate rock increased the crop values $27 and $36, respectively, on the limed and unlimed plats, or 56 and 82 per cent., respectively, of the increase caused by the dissolved phosphate rock or acid phosphate.

Double superphosphate was inferior to dissolved phosphate rock, especially on the unlimed plats.

Considering the average with the limed and unlimed soil, dissolved phosphate rock increased the crop values to about the same extent as the somewhat similar dissolved boneblack.

Thomas slag phosphate gave the greatest increase of any phosphate on the unlimed soil. This was doubtless due to the fact that it contained about 40 per cent. of calcium oxid, which was useful in reducing the soil acidity. Even on the limed plat, it was probably similarly useful to some extent for lime was never added to these plats in amounts which sufficiently neutralized the soil for the best growth of certain crops. It must not be forgotten, therefore, that this phosphate served as a source of lime as well as of phosphorus.

Fine ground bone was nearly as effective as Thomas slag phosphate even on the unlimed plats, which indicates that it was physiologically basic in a marked degree as well as being highly available as a source of phosphorus in the unlimed soil. The nitrogen in the bone may have served a useful purpose in spite of the fact that nitrate of soda was added liberally. If so, the nutrient effect should not be attributed solely to the phosphorus.

On the limed plats, dissolved boneblack gave the largest increase of any nitrogen-free phosphate. It should be stated, however, that the dissolved boneblack plats, which are located at one end of the area devoted to this experiment, appear somewhat unlike the remainder of the area, which is very uniform from plat to plat.

Dissolved bone, which however also contains nitrogen, gave the largest crop values secured from any limed plat.

Having considered the crop increases accompanying an equal application of phosphorus in the different phosphates, there remains to be discussed somewhat the increase in crop values during the twenty year period per one dollar expended for each phosphate, as given also in Table XXI. This must be done with a clear recognition of certain considerations; otherwise, false impressions will be gained.

In the first place, it must be borne in mind that in this comparison the advantage lies with the phosphates in which the least money was invested, for the reason that the size of the crop was frequently determined in large measure by other factors than the supply of available phosphorus, such as lack of water, injury from pests, etc. In such cases, the larger amount of available phosphorus supplied by the more expensive phosphates does not have an opportunity to exert its full effect, and the returns for a dollar expended tend to be less favorable than with the cheaper sources.

Again, it may have been true, during certain years, when rather liberal applications were made, that the most available sources supplied more phosphorus than was necessary for the amount of growth made, which would be to their economic disadvantage. It is generally true that the nearer a crop is forced to its maximum growth by the addition of manures, the less will be the returns from a dollar expended for those manures. Raw phosphate rock, for example, caused only about 70 per cent. as much average increase in crop as dissolved phosphate rock, but gave considerably higher returns per dollar expended for the phosphates alone, for it cost only about half as much.

The non-fértilizer expenses, however, are nearly as great for the small crop as for the larger one, so that if these items were included in the dollar expenditure, the relative returns in the case of the various phosphates would be quite different from those based upon the expenditure for only the phosphates.

The present experiment was conducted primarily to determine the relative availability of a given amount of phosphorus. Undoubtedly a clearer idea of the relative returns from a given amount of money invested in different phosphates may be gained by attempting to supply such amounts as will produce crops of similarsize. Under such circumstances the previous considerations would not be important.

With these cautions in mind, it may be noted that fine ground bone, at the cost of only its phosphorus and not of its nitrogen, gave in the limed soil, better returns per dollar expended for it than any other source of phosphorus. The reader is again reminded, however, that possibly the nitrogen which was not included in the cost may nevertheless have increased the crop in some instances, even though applied liberally in another form.

On the unlimed soil the raw phosphate rock gave the largest returns for a dollar expended for phosphorus, but the acidity was too great for economic crop production. A pound of phosphorus in this material costs about half as much as in dissolved phosphate rock, and it increased the crop values a little more than half as much in the limed soil, but about eight-tenths as much in the unlimed soil. A very favorable relative return is shown, therefore, if all the expense factors are *not* taken into consideration. If, however, an allowance were to be made for rental and for the non-manurial expense of growing the crops, which items are practically the same whether the crop be large or small, the economic advantage in securing the larger crop would be seen at once. It should of course be recognized that undoubtedly raw phosphate rock would have produced larger crops had more of it been used.

Thomas slag phosphate was useful not only as a source of phosphorus, but in many instances, at least, as a source of calcium oxid for neutralizing purposes. The entire cost of the material was therefore included. It and the dissolved bone, the nitrogen of which may have had some effect on growth but the cost of which was not included, ranked third and fourth, respectively, from the standpoint of a dollar expended for them.

The non-nitrogenous dissolved phosphates, which rank next, need not be considered individually in this connection, apart from the table.

In connection with any statements which may be made in a general way regarding the relative availability of phosphorus in this or that phosphate, it must always be remembered that the nature of the individual crop has a large influence on that availability.

This may be shown by grouping the results secured in 1903 from the market garden crops, peas, turnips, cabbage, tomatoes and squashes, for comparison with those obtained from the general farm crops, crimson clover, potatoes, Japanese millet, oats and golden millet. All were grown on small areas crosswise the various phosphate plats one year after such application of phosphorus had been made as would equalize the amount added to each plat during the experiment, and all crops had the same manurial treatment.

The relative availability of the phosphorus for the two preceding groups of crops, based upon the value of the crops of only a single year, was as follows:

Source of phosphorus added previously.	*Market-garden crops.*	*General farm crops.*
Dissolved bone	100	100
Fine ground bone	94	82
Thomas slag phosphate	84	78
Dissolved boneblack	77	54
Dissolved phosphate rock	71	77
Double superphosphate	69	43
Roasted Redonda phosphate	22	34
Raw phosphate rock	21	46
Raw Redonda phosphate	(—) 3	11
No phosphate	0	0

The foregoing shows that the phosphorus of the raw phosphates given at the bottom of the table was much less available for the market-garden crops than for the general farm crops. The phosphorus in raw phosphate rock for example was only 30 per cent. as available as that in the dissolved phosphate rock, for the market garden crops, whereas it was 60 per cent. as available for the general farm crops.

In Rhode Island, phosphoric acid costs over twice as much in the dissolved as in the raw phosphate rock; nevertheless, the use of the former appears to be more economical where quick results are desired, such as with truck crops. An application in 1913 of even 2¼ times as much phosphorus in raw as in dissolved phosphate rock gave less than half as large a crop of table beets. For certain long-season crops, however, the present experiment indicates that raw phosphate rock may be used economically to increase the phosphorus-content of the soil where quick returns are not necessary. The results of an experiment now being conducted with raw and dissolved phosphate rock on an equal cost basis will help decide which is the more economical to use in such circumstances.

In Table VIII may be found the increase in crop values during the first eleven years of the experiment, due to the phosphorus which was then applied, and in Table XXI, the increase including also the last nine years when no more phosphorus was added.

In the limed soil, dissolved phosphate rock produced during the eleven-year period 50 per cent. of the total increase in crop values, and the raw phosphate rock, 42 per cent. Again, in the unlimed soil, the dissolved phosphate rock produced 56 per cent., and the raw phosphate rock 53 per cent., during that period.

If the system of cropping, the climatic conditions, and the rate of availability of the phosphorus had been the same in the two periods, 55 per cent., or eleven-twentieths, of the total increase in crop values would have been expected during the eleven-year period, provided also that the amount of available phosphorus was always the factor limiting growth. The fact that usually less than 55 per cent. of the total increase in crop values was secured during that period does not show that the rate of availability of the phosphorus was less during the period of application than later, for the conditions referred to above did not exist. For example, the second application of lime in 1903 probably increased the availability of the residues from the phosphatic applications and thereby augmented the increase in crop values during the second period.

It must also be recognized that even the *comparative* after-effect of the raw, and the dissolved, phosphate rock can be only approximately measured by the increase in crop values, for here again the system of cropping would influence the relation as has been shown by the differences in the comparative after-effects of the two phosphatic materials, depending upon the kind of crop.

Although the data do not enable a detailed discussion of the relative after-effects of the different phosphates, they do show that in general this effect of the phosphatic applications is of such magnitude that continued tenure of the land becomes highly desirable from the standpoint of economy.

Chemical Information Concerning the Soil.

The relative effect of different phosphates depends so much upon the nature of the soil that attention will now be directed to such laboratory determinations made from time to time as may serve to throw light on the problem under consideration.

The soil upon which the three experiments were conducted was of the same general nature. It was classified as Miami silt loam by the U. S. Bureau of Soils and is composed of glacial drift of granitic origin. Hot hydrochloric acid of 1.115 specific gravity dissolved about 4.5 per cent. of aluminic oxid, 3.5 per cent. of ferric oxid, 0.57 per cent. of calcium oxid, and 0.15 per cent. of phosphoric acid. Only 0.02 per cent. of calcium oxid was extracted by carbonated water. The soil contained 3 to 4 per cent. of humus of which considerable was extractable directly by ammonium hydroxid without previous treatment with dilute hydrochloric acid.

Considerable chemical work was done on samples of soil and crops collected in 1903 in connection with Experiment III, one year after the application of the phosphates had ceased.* It was then found, according to the Veitch limewater method that no other phosphate had left the surface soil so nearly neutral as Thomas slag phosphate, requiring .08 and .11 per cent. of calcium oxid to neutralize the limed and unlimed soil, respectively, whereas certain plats required twice these amounts. In the spring of 1914 a foot-acre of soil required for neutralization according to the Jones calcium-acetate method† an average of 1,900 pounds of calcium oxid in case of the limed plats and 2,800 in case of the unlimed plats. The average amount of phosphoric acid extracted from the soil by different solvents was about as follows:

	Per cent. of P_2O_5
Nitric acid, $\frac{N}{5}$	.015
Nitric acid, $\frac{N}{25}$	.003
Ammonium hydroxid, $\frac{N}{5}$	.035
" " $\frac{N}{25}$	.022
" " $\frac{N}{100}$	.004

From .38 to .59 per cent. of combined ferric and aluminic oxids were dissolved from the various plats by $\frac{N}{25}$ nitric acid, and even $\frac{N}{75}$ acid dissolved .20 per cent., most of which was apparently aluminic oxid. Ten times as much aluminic and ferric oxids as calcium oxid was dissolved in $\frac{N}{5}$ nitric acid, or in the relation of 1.456 to .146 per cent., even from plats which had received two tons of air-slaked lime per acre in previous years. It seems evident from these relations that phosphorus must enter into combination quite extensively with iron and aluminum and become more slowly available than if the conditions favored its remaining in the soil in combination with calcium. The very satisfactory returns from bone, for example, which were better than from dissolved phosphate rock may be attributable to the fact that the soluble phosphorus of the latter enters more largely into combination with iron and aluminum than does the insoluble phosphorus of bone.

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*An. Rpt. 18, 253–285.

†American Fertilizer, 39, 29 (1913).

It may have been observed that from the limed soil even less total yields were secured, during the Experiment III, where 738.6 pounds of phosphoric acid per acre were added in raw Redonda phosphate than where no phosphorus was added; and inasmuch as such crops from these plats as have been analyzed contained about the same average percentage, it follows that in the two cases practically the same amount of phosphorus was probably removed from the soil in the crops. Provided there was no difference in the amount removed in other ways, all of the added phosphorus should be represented in the increased phosphorus content of the soil. It was considered of interest to have this content determined in certain plats, so in the spring of 1914 soil samples were taken to the depth of one foot, the material coarser than 1 mm. sifted out, and the following percentage of phosphoric acid was found in the moisture-free dry soil, by ignition, and solution in acid.*

	Limed. %	Unlimed. %
Dissolved phosphate rock	.175	....
Raw phosphate rock	.200	.196
Raw Redonda phosphate	.184	.210
Roasted Redonda phosphate	.178	.190
No phosphate	.174	.210

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*The determinations were made by L. P. Howard.

A foot-acre of the dry soil weighs about 3.1 million pounds, of which about 89 per cent., or 2.76 million pounds is finer than 1 mm. The 738.6 pounds of phosphoric acid which was added per acre to each phosphate plat during the experiment is therefore equivalent to .027 per cent. of the fine soil. Nevertheless the soil from the unlimed raw Redonda phosphate plat contained no greater percentage of phosphoric acid than that from the check plat, even though not much more was removed in the crops. In case of the soil from the corresponding limed plats, there is an increase of only .010 per cent. instead of .027 per cent. As practically the same amount of phosphorus was removed in the crops taken from the two plats, a loss of phosphorus must be accounted for in the drainage water, in dust, or in a gaseous condition, if the analysis of the fine soil is accepted as an accurate measure of the conditions.

Inasmuch, however, as there was an oversight in not determining the amount of material coarser than 1 mm., there is no certainty that the percentage of such material may not have differed enough to render certain comparisons based upon the percentage in fine soil somewhat inaccurate. On this account, too much emphasis should not be placed on small differences in the foregoing percentages. It may be seen in general, however, that the phosphate plats were no richer in phosphorus after the 20 years of cropping than those which received only nitrogen and potassium.

Although there has been no record kept of the additional phosphorus removed in the crops from the phosphate plats, it seems probable that the greater part of the added phosphorus must have been removed in that way.

Summary.

This bulletin contains the details of the unpublished results, and a summary of the published results, secured in all the field experiments conducted at the station previous to 1914 with different sources of phosphorus.

Experiment I was a six-year comparison of Chincha and Lobos guanos, ground bone and dissolved phosphate rock applied so as to furnish the same amount of phosphorus; the nitrogen and potassium of the guanos being matched by using nitrate of soda and muriate of potash to supplement the bone and dissolved phosphate rock. Usually the three manurial elements were probably somewhat deficient so that phosphorus was not the only element affecting growth. During most of the experiment the soil was too acid for the best growth of some of the plants. The total yields from the ground bone, guano, and dissolved phosphate rock sections were 9094, 8747 and 8420 pounds, respectively.

In Experiment II, Thomas slag phosphate, Lobos guano, ground bone, and dissolved phosphate rock were compared for seven years on an equal phosphorus basis in the presence, in this case, of liberal amounts of nitrogen and potassium, with the hope that the natural supply of phosphorus would prove so deficient that this element would control the growth. This condition was not attained, however, to a degree which warranted definite conclusions.

Twenty years were devoted to experiment III for the purpose of determining the relative availability of equal amounts of phosphorus in nine different phosphates applied during the first half of the experiment, with liberal amounts of nitrate of soda and muriate of potash, to limed and unlimed land. During the last half only nitrogen and potassium were applied in order that the after-effects of the different sources of phosphorus might be studied.

The results of the first five years of this experiment are tabulated by themselves because during that period the phosphates were added on the basis of equal cost. The Thomas slag phosphate and the ground bone were superior even to the dissolved boneblack and the dissolved bone on the unlimed soil, the reverse being true in case of the limed soil. Dissolved phosphate rock or acid phosphate ranked fifth in both the limed and unlimed soil, being markedly superior to the raw phosphate rock or floats.

Subsequent to the five-year period at the beginning of experiment III, the plan was changed so that equal amount of phosphorus instead of equal cost should eventually be the basis of comparison. The phosphorus was finally equalized by the applications of 1902, after which no more phosphorus was added. The second tabulation of the results includes those from the beginning to 1904. The most available phosphorus in both limed and unlimed soil was apparently that in Thomas slag phosphate, ground bone and dissolved bone; it should be noted, however, that the basicity of the former was doubtless advantageous in both cases, and that the nitrogen in the bones may have been useful in spite of the liberal applications of nitrate of soda. The dissolved boneblack and dissolved phosphate rock ranked next and were again considerably superior to the raw phosphate rock.

The final tabulation of experiment III summarizes the entire twenty years and differs from the preceding one in that it includes also the after-effects of the phosphates. These effects are very striking and show the importance of continued tenure of the land. They left the rank of the different phosphates practically unchanged in case of the unlimed plats, the main change with the limed plats being that the dissolved boneblack was placed among those of first rank. The dissolved phosphate rock holds an intermediate place, being decidedly superior on both the limed and unlimed soil to the phosphates to be considered next. The double superphosphate seemed to need considerable lime for its greatest efficiency, for only on the limed soil did it rank next to the dissolved phosphate rock, being decidedly inferior even to the raw phosphate rock in case of the unlimed soil. With the limed soil, roasted Redonda phosphate was somewhat superior to the raw phosphate rock, although decidedly inferior with the unlimed soil. The raw Redonda phosphate was practically valueless; in fact there was evidence of a deleterious effect in the limed soil.

On account of the fact that the phosphorus cost only about half as much in the raw phosphate rock as in most of the other sources in experiment III, it ranks, from the standpoint of the cost of only the phosphorus, with that in Thomas slag phosphate and the bones. Owing to the smaller crops produced, however, it suffers by comparison with the phosphorus in the better phosphates when all the cost factors are considered.

Experiment III affords an opportunity for observing the effects of the three tons of slaked lime per acre applied in 1894, 1903 and 1911 to the limed phosphate plats, in comparison with their effect where no phosphorus was used. In the latter case, the increase in the value of the crop during the twenty years, due to the lime, was about $400 per acre; whereas with the insoluble phosphates, ground bone, Thomas slag phosphate, raw phosphate rock and raw Redonda phosphate it was $330 and less; and with the other phosphates the increase was from $442 with the dissolved phosphate rock to $590 with the double superphosphate.